Basic Red 18 and Remazol Brilliant Blue R biosorption using Russula Brevipes, Agaricus Augustus, Fomes Fomentarius

Ceren Arslantas¹, Islem M‘barek²,³, Mohammed Saleh², Zelal Isik², Sadin Ozdemir⁴, Abdurrahman Dundar⁵ and Nadir Dizge²,∗

¹Department of Environmental Engineering, Gebze Technical University, Gebze 41440, Turkey
²Department of Environmental Engineering, Mersin University, Mersin 33343, Turkey
³Laboratory for the Application of Materials to the Environment, Water and Energy (LR21ES15), Faculty of Sciences of Gafsa, University of Gafsa, Tunisia
⁴National Agricultural Research Center (NARC), Jenin, Palestine
⁵Food Processing Programme, Technical Science Vocational School, Mersin University, Mersin 33343, Turkey

∗Corresponding author. E-mail: ndizge@mersin.edu.tr

ABSTRACT

In this study, the adsorption abilities of Russula Brevipes (RB), Agaricus Augustus (AA), and Fomes Fomentarius (FF) were evaluated in Basic Red 18 (BR18) and Remazol Brilliant Blue R (RBBR) biosorption from textile effluent. The adsorbents were characterized via Scanning Electron Microscopy (SEM), Energy Dispersive Spectrometer (SEM-EDS), and Fourier transform infrared spectroscopy (FT/IR). Fomes fomentarius present a low sorption capacity contrary to the two other fungi (RB and AA). RB and AA were selected as potential adsorbents for BR18 and RBBR, respectively. The maximum BR18 removal efficiencies for 10, 25, and 50 mg/L were obtained after 60 min to be 90, 88, and 86%, respectively. The RBBR adsorption efficiencies were 96.4, 96, and 90% for dye concentrations of 10, 25, and 50 mg/L. The adsorption of BR18 onto the RB biomass followed the Freundlich isotherm, while Langmuir is the best isotherm for RBBR sorption’s elucidation onto AA fungus biomass. The removal of BR18 by BR biomass was found to follow the pseudo-second-order. In contrast, the adsorption of RBBR onto the AA biomass followed Lagergren’s pseudo-first-order. For both adsorbents, the adsorption was exothermic, feasible, and spontaneous in nature. Finally, the dyes biosorption process was perfectly achieved onto fungi biomass via physisorption.

Key words: Basic Red 18, biomass of fungi, biosorption, Remazol Brilliant Blue R

HIGHLIGHTS

• Three fungus Russula brevipes (RB), Agaricus augustus (AA), and Fomes fomentarius (FF) were used for dye adsorption.
• Basic Red BR18 and Remazol Brilliant Blue RBBR dyes were tested for adsorption.
• Freundlich describe perfectly the sorption process of BR18 dye onto RB fungus.
• Langmuir is the best isotherm for RBBR sorption’s elucidation onto AA fungus biomass.
1. INTRODUCTION

Although the textile industry shows subsequent growth and contributes to the countries economies, it still suffers from its toxic effluent (Dos Santos et al. 2007). Indeed, textile wastewater is a seriously harmful industrial effluent (Ogugbue & Sawidis 2011). Textile wastewater is one the most polluting source since it has a hazardous mixture of varied toxic compositions; heavy metal, bleaching reagents, sterilizer, dye, etc. (Ben Mansour et al. 2012; Gita et al. 2017). Dye is the basic component in textile manufacturing and one of the most toxic and stiff elements. Thus the dye removal from the textile wastewater before its discharge is an obligation (Rawat et al. 2018). Several physical, chemical, and combined physicochemical treatments were employed (Collivignarelli et al. 2019), Advanced oxidation processes (AOP’s) were also applied in dye degradation (Pelin et al. 2020; Saleh et al. 2021a). Though, the removal of dye via various processes showed some limitations, basically on effectiveness and financial charge (Hadj et al. 2019). Activated sludge (Osman et al. 2004) and activated clay (Hsu et al. 1997) were utilized in the dye adsorption process. Indeed, biosorption seems the most suitable process that estems with the green chemistry concept. The biosorption passes the mentioned limitation by providing more efficient sorption for the contaminated water with the lowest cost (Robinson et al. 2001). This concept has attracted research attention since 1980, thanks to sorbent availability, effortless accessibility, and environmentally friendly property (Saleh et al. 2019).

Biosorption is an efficient method for dye sorption, various organic pollutants, and heavy metals (Schiewer & Wong 2000; Walker & Weatherley 2000). Sundry types of microorganisms such as; bacteria, algae, and fungi were used for decolorizing dyes from the industry’s effluents (Fu & Viraraghavan 2000; Kumari & Abraham 2007; Jamee & Siddique 2019). Admittedly, biosorption via microorganism present advantages, but its sorption capacity depends on which type of biomass was used (Pankaj & Harleen 2011). Because of their availability, Fungus seems to be the best adsorbent among the microorganism. Fungus owns interesting mechanical characterization against abrasion, and they are chemically stable in most acidic and alkaline mediums (Mittal & Gupta 1996). The fungi may be used in two forms; the dead and the live fungi. The dead biomass is more effective for dye and organic pollutant sorption compared with live fungi (Tsezos & Bell 1989). Nityanand et al. (2006)
utilized Fomes fomentarius and Phellinus igniarius in methylene blue (MB) and rhodamine B (RB) biosorption (Nityanand et al. 2006).

In this study, the adsorption abilities of Russula Brevipes (RB), Agaricus Augustus (AA), and Fomes Fomentarius (FF) were evaluated in Basic Red 18 (BR18) and Remazol Brilliant Blue R (RBBR) biosorption from textile effluent. These dyes are the most commonly used industrial toxic dye in textile manufacturing. The Basic Red 18 is an azo cationic dye that presents more than one functional group and is used basically for the textile industry (Fil et al. 2013). Remazol Brilliant Blue is a harmful organic dye (Mechichi et al. 2000). RBBR, which contains anthracene derivatives (Eichlerová et al. 2007), is frequently used in the textile industry because of its high solubility in aqueous solutions (Torgut et al. 2017). Though the removal of Basic Red 18 (BR18) and Remazol Brilliant Blue R (RBBR) from textile wastewater was done efficiently via various processes, these last showed some limitations (Hayat et al. 2015; Routoula & Patwardhan 2020). Therefore, the biodegradation of RBBR, BR18 dye in a biological-based, safe, and eco-friendly method had been preferred more than the other processes (Mallet 2010; Paz et al. 2017).

In previous studies, Aspergillus carbonarius (AC) and Penicillium glabrum (PG) were employed for BR18 decolorization (Bouras et al. 2017; Isik et al. 2019). RBBR dye was adsorbed by T. citrinoviride, T. koningiopsis, and Pestalotiopsis (Achmad & Mohamad 2021). Nonetheless, to the best of our knowledge, there is no reported paper on Russula brevipes, Agaricus Augustus, and Fomes fomentarius's evaluation for BR18 and RBBR biosorption abilities. Moreover, the first two fungi present good aptitudes for (BR18) and (RBBR) sorption, contrary to Fomes fomentarius, which does not show any ability for the tested dyes.

2. MATERIALS AND METHODS

2.1. Materials

Basic Red 18 (BR18) and Remazol Brilliant Blue R (RBBR) were obtained from Sigma–Aldrich. The chemical structure and some properties of the BR18 and RBBR dyes are presented in Table 1. Russula Brevipes (RB), Agaricus Augustus (AA) and Fomes Fomentarius (FF) were obtained from Environmental Biotechnology Laboratory, Mersin University, Turkey. For pH adjustment, sodium hydroxide (NaOH, Sigma–Aldrich) and hydrochloric acid (HCl, Sigma–Aldrich) were used.

Table 1 | Chemical structures and some properties of the dyes

| Chemical Name            | Chemical Structure | Molecular Formula       | Molecular Weight (g/mol) | UV absorption \( \lambda_{max} \) (nm) |
|--------------------------|--------------------|-------------------------|--------------------------|--------------------------------------|
| Basic Red 18 (BR18)      | ![Chemical Structure](image) | C_{19}H_{25}N_{5}C_{12}O_{2} | 426.34                   | 484                                  |
| Remazol Brilliant Blue R (RBBR) | ![Chemical Structure](image) | C_{22}H_{18}N_{2}Na_{2}O_{11}S_{3} | 626.53                   | 590                                  |

2.2. Preparation of dead fungi biomass

The fungal biosorbents Russula brevipes, Agaricus augustus, and Fomes fomentarius were collected in Mersin, Turkey. They were brought to the laboratory and washed three times with deionized water to remove contaminants and dried in oven at 25 °C for 168 h. After drying step, they were powdered using a grinder and dried at 105 °C for 24 h. The dried, powdered biomass was stored in a desiccator without any further chemical or physical treatment.

2.3. Batch experiments

The first step in the batch experiments was the selection of the fungus biomass. The fungus selection experiments were conducted using the three bio sorbents; RB, AA, and FF, and two dyes; BR18 and RBBR. The dyes (BR18 and RBBR) were prepared in a concentration of 25 mg/L and a volume of 50 mL. Bio sorbents were added at the same doses (1 g/L) and agitated at 150 rpm for 1 h at room temperature. The removal efficiency for the
concentration of the dye was calculated using Equation (1).

\[
\text{Removal (\%)} = \left( \frac{\text{Initial Concentration} - \text{Final Concentration}}{\text{Initial Concentration}} \right) \times 100
\]  

(1)

The effect of pH on BR18 and RBBR adsorptions onto the biomasses was explored on a pH range of 2–10. 1 g/L of the adsorbents was added in a 50 mL solution contains 25 mg/L dyes concentration. The adsorptions occurred at room temperature (25 ± 2 °C) with a rotational speed of 150 rpm for 60 min.

The effects of the adsorbents doses were investigated by adding different amounts (0.25–2.0) g/L to 50 mL solutions with dyes concentrations of 25 mg/L at the optimum pH value. The experiments extended over 60 min and occurred at an agitation speed of 150 rpm at room temperature (25 ± 2 °C).

The effects of contact time and the initial concentration on the adsorption process were explored. Known amounts of the biomasses (1 g/L BR and 0.5 g/L AA) were inserted into 50 mL solutions with different initial concentrations (10, 25, 50 mg/L). The experiments extended over 60 min and occurred at an agitation speed of 150 rpm at room temperature (25 ± 2 °C).

2.4. Adsorption isotherms

The isotherms experiments were determined as defined previously (Saleh et al. 2021b). The characteristic of the adsorption equilibrium was estimated using Langmuir (Equation (2)) (Langmuir 1918) and Freundlich (Equation (3)) (Freundlich 1906) isotherms equations.

\[
q_e = \frac{Q_{max} \times K_L \times C_e}{1 + K_L \times C_e}
\]  

(2)

\[
q_e = K_F \times C_e^{1/n}
\]  

(3)

where, \(q_e\) and \(C_e\) are the adsorption capacity (mg/g) and the concentration (mg/L) at the equilibrium. \(K_L\) and \(K_F\) are Langmuir and Freundlich respectively. \(Q_{max}\) is the maximum adsorption capacity (mg/g) and \(1/n\) is the heterogeneity factor.

2.5. Kinetic studies

Kinetic studies were conducted at different contact times (from 0 to 60 min) using 50 mL dye solution volume and \(C_0\) of 10, 25 and 50 mg/L at room temperature. After each experiment, the dye concentrations were spectrophotometrically determined at 484 nm for BR18 and 590 nm for RBBR. The kinetic curves were described by the nonlinear forms of the pseudo-first-order model (Lagergren 1898) and the pseudo-second-order model (Ho et al. 1996). The nonlinear forms of pseudo-first-order model and the pseudo-second-order model are shown in Equations (4) and (5), respectively.

\[
q_t = q_e(1 - e^{-K_1t})
\]  

(4)

\[
q_t = \frac{q_e^2K_2t}{1 + q_eK_2t}
\]  

(5)

where, \(q_e\) is adsorption capacity at time t (mg/g), t is the time (min), \(K_1\) and \(K_2\) are the first and second order kinetic constant, respectively.

2.6. Characterization of biosorbent

Scanning Electron Microscopy (SEM, Zeiss Supra 55-Germany) analysis was carried out to analyze the biosorbent surface morphology and surface elemental characters were analyzed at the same spot via Energy Dispersive Spectrometer (SEM-EDS, Zeiss Supra 55-Germany) simultaneously. The functional groups at the adsorbents surfaces were scanned at bands 450–4,000 cm\(^{-1}\) by Fourier transform infrared spectroscopy (FT/IR-6700, Jasco).
3. RESULTS AND DISCUSSION

3.1. Characterization

Scanning Electron Microscopy (SEM) analysis was carried out to analyze the biosorbent surface morphology. The Russula Brevipes (RB) consisted of non-uniform random layers that made the surface rough and heterogeneous with stream-like channels (Figure 1(a)). After the adsorption process, the channels were filled with dye particles making the surface smoother (Figure 1(b)). The surface of Agaricus Augustus (AA) is also coarse and heterogeneous (Figure 1(c)). The adsorbed dye reduced the heterogeneity of the AA surface. No spaces were noticed at the surface of AA after the adsorption since the dyes filled the spaces between the AA pieces (Figure 1(d)).

![Figure 1](image1.png)  
**Figure 1** | SEM images for (a) Raw RB (b) RB after the adsorption of BR18 (c) Raw AA (d) AA after the adsorption of RBBR.

![Figure 2](image2.png)  
**Figure 2** | FTIR spectrums for (a) Raw RB and (b) raw AA.

The FT-IR spectra of both raw fungal biomass RB and AA present common peaks. At 3,263 cm\(^{-1}\), intense peaks are observed on both spectra which are related to (–OH) stretching also it may have represented the stretching of (–NH) groups. Then, other common peak at 2,924 cm\(^{-1}\) interrelated to (C–H) stretching vibrations. At 1,632...
cm$^{-1}$, one peak detected on raw RB spectra, it is relative to bending (N–H) groups. At range of wave length of 1,555 cm$^{-1}$, 1,374 cm$^{-1}$, two peaks were observed and related respectively to (N–H) bending, (–CH3) elongation. Moreover, the peak observed at 533 cm$^{-1}$ representing (C = O) bending vibration. Finally, a peak identified at 470 cm$^{-1}$ related to C–N–C scissoring group. These several functional groups present on both fungal biomass RB and AA (Bayramoglu & Arcaülay 2008).

3.2. Fungal selection
The removal efficiencies and the adsorption capacities are shown in Figure 3. For BR18, the three biomasses had relatively high removal efficiencies. However, RB had the maximum removal efficiency (84%) and adsorption capacity (21 mg/g). The removal efficiencies for AA and FR were 69 and 59%, respectively (Figure 3(a)). The maximum removal efficiency and adsorption capacity of RBBR dye were obtained when the AA biomass was used as an adsorbent. The removal efficiencies and the adsorption capacities for RB and FR were very low (Figure 3(b)). Accordingly, RB was selected for BR18 adsorption while AA was utilized in the adsorption of RBBR.

![Figure 3](image-url) The removal efficiencies and the adsorption capacities for RB, AA, FF biomasses for (a) BR18 (b) RBBR dyes at experimental conditions (pH 6, initial concentration 25 mg/L, adsorbent amount 1 g/L, and contact time of 60 min).

3.3. Effects of pH
The effects of pH on the adsorption capacity and the removal efficiency for BR18 and RBBR are shown in Figure 4(a) and 4(b), respectively. The protonation and deprotonation process at the biomass surfaces is controlled by the hydrogen ion concentration (Saleh et al. 2021c). The adsorption of BR18 onto RB biomass increases with the increases in the pH until pH 6. The removal efficiency and the adsorption capacity were 84% and 21 mg/g, respectively. Beyond that (pH 6), the removal efficiency and the adsorption decreased with the increases in pH. Koyuncu & Kul (2020) noticed that the acidic conditions increase the positive charge at the nonliving *Pseudevernia furfuracea* surface, which repel the cationic dyes and decreases the efficiency (Koyuncu & Kul 2020). At higher pH values, the -OH strong strives for the active sites on the RB surfaces. Another possible reason is that the -OH may be exchanged with dye ions. The maximum removal efficiency of the cationic dye methylene blue by *Aspergillus parasiticus* was obtained at a pH value of 8 (Bouras et al. 2021). For RBBR, the maximum removal efficiency and adsorption capacity were obtained at pH 2, and the pH increase reduced the removal efficiency and the adsorption capacity. The AA biomass achieved an uptake of 78% and an adsorption capacity of 19.5 mg/g. Isik et al. (2021) had successfully utilized polyethyleneimine modified calcium alginate beads in RBBR adsorption (Isik et al. 2021a). In their works, the removal efficiency decreased with the increases in pH values. Pelosi et al. (2014) demonstrated the pH-RBBR removal curve by the deprotonation of oxygen present in dye at high pH levels (Pelosi et al. 2014). Won et al. (2005) explained the high removal efficiency at lower pH values by the electrostatic forces (Won et al. 2005). The biomass surface gets positively charged at lower pH values, which builds interaction between the negatively charged dye anions and the AA biomass surface.
3.4. Effects of adsorbent dose

The effects of the adsorbent doses were investigated and the changes in the removal efficiencies and the adsorption capacities for BR18 and RBBR are shown in Figure 5(a) and 5(b), respectively. For BR18, the removal efficiency increased from 66% to 84% at adsorbent doses of 0.25 and 1 g/L, respectively. After the adsorbent amount of 1 g/L, the increases in the adsorbent doses had little changed the removal efficiency. In contrast, the adsorption capacity decreased with the adsorbent doses increases. The same trend was noticed in the adsorption of RBBR. The removal efficiency increased from 90% at 0.25 g/L dose to reach 96% at 0.50 g/L. Beyond that dose, no noticeable changes were recorded in the RBBR removal efficiency. Also, the adsorption capacity decreased sharply at higher adsorbent doses. Yalvaç & colleagues (2021) presented similar trends for crystal violet removal by Centaurea Solstitialis and Verbascum Thapsus (Yalvaç et al. 2021).

3.5. Effects of initial concentration and the contact time

The changes in the removal efficiencies and the adsorption capacity for BR18 and RBBR corresponding to the initial concentration and the contact time are shown in Figure 6(a)–6(d), respectively. The adsorption of BR18 onto BR and the adsorption of RBBR onto AA can be considered fast processes. The removal efficiencies sharply increased after the first 5 min for both adsorbents. For 10, 25, and 50 mg/L dyes, the removals of BR18 reached after 5 min 78, 84, and 74%, respectively. The uptakes of RBBR after 5 min for the same initial concentrations were 65, 77, and 75%. The dyes uptakes continued increasing however with a flatter shape. As discussed previously by Saleh et al. (2021) (Saleh et al. 2019) and Isik et al. (2021b), at the start of the adsorption process, the active sites present at the BR and AA surfaces were empty and ready to capture the dyes. At that time the mass...
transfer from the adsorbate to the adsorbent was high. Thus the removal efficiencies increased sharply. With time, the ready active sites numbers decreased as a result from the attaching dyes, so the removal trend became flatter till the steady-state conditions at 60 min. The maximum BR18 removal efficiencies for 10, 25, and 50 mg/L were obtained after 60 min to be 90, 88, and 86%, respectively. The RBBR adsorption efficiencies were respectively 96.4, 96, and 90% for dye concentrations of 10, 25, and 50 mg/L. The adsorption capacities for BR18 dye at initial concentrations of 10, 25, and 50 mg/L were respectively 9, 22, and 43 mg/g. At same initial concentrations, the RBBR adsorption capacities were 19.3, 48, and 90 mg/g. As the initial concentration increased, the adsorption capacity also increased. The present of high concentration in the adsorbate side increases the mass transfer between the adsorbate towards the adsorbent because of the diffusion force. Thus the adsorption capacity increased.

3.6. Adsorption isotherm

Langmuir and Freundlich’s models were used to study the adsorption isotherms for BR18 removal by BR and RBBR removal by AA biomass. To increase the precision and to avoid any error in data transformation process, Origin software (version 2019) was utilized to fit the non-linear forms for both isotherm models (Boulinguiez et al. 2008; Belhachemi & Addoun 2011). Table 2 shows the results fitting to the non-linear forms of the isotherms.

The removal of BR18 by the RB biomass has high correlations coefficients for both isotherms. However, Freundlich had a higher correlation coefficient and lower error value. According to Freundlich isotherm, the adsorption of BR18 onto the RB biomass occurred on a heterogeneous surface through multilayers (Zhou et al. 2019). In contrast, the adsorption of RBBR onto AA biomass was found to follow Langmuir isotherm for
the same reasons. In this isotherm, the adsorption occurs in a homogenous monolayer, and the adsorption is limited by finite numbers of active sites at the adsorbent surface. According to Langmuir isotherm, no interaction between the adsorbed matters will be present (Siwek et al. 2019). The adsorption of malachite green onto low-cost adsorbent from the exudate of Lannea coromandelica (Houtt) also followed the Langmuir isotherm (Mate et al. 2021). For both BR18 and RBBR, the adsorption was found to be favorable since the n-factor lies in the range of 1–10, and RL (RL = 1/ (1 + KL × Co)) is between 0 and 1.

3.7. Adsorption kinetics

Laguerre’s pseudo-first-order and pseudo-second-order models were used to represent the kinetic terms for the adsorptions of BR18 onto BR and RBBR onto AA. The nonlinear curves for Laguerre’s pseudo-first-order and pseudo-second-order models for BR18 and RBBR dyes are shown in Figures 7 and 8, respectively. The removal of BR18 by BR biomass was found to follow the pseudo-second-order (higher R^2 and lower chi-square error). Yildirim (2020) utilized a crosslinked Pleurotus ostreatus-based bio-composite in malachite green (MG) and methylene blue (MB) adsorption. The adsorptions of both cationic dyes were found to follow the pseudo-second-order (Yildirim 2020). In contrast, the adsorption of RBBR onto the AA biomass followed Laguerre’s pseudo-first-order. Bouras & colleagues (2021) stated that the adsorption of phenol red dye onto Aspergillus parasiticus followed the Laguerre’s pseudo-first-order (Bouras et al. 2021). The kinetic parameter and the statistical error calculations for the fitting process were obtained with the aid of Origin software (version 2019), as shown in Table 3.

3.8. Adsorption thermodynamic

The Gibbs free energy, enthalpy, and entropy for the removal of BR18 by BR biomass and RBBR by AA biomass were determined at different temperatures (298, 303, 308, and 313 K). The relationship between the 1/T and the ln K is presented in Figure 9(a) and 9(b) for BR18 and RBBR, respectively.

Table 2 | Isotherms fitting results

| Isotherm | Parameter | BR18 onto BR | RBBR onto AA |
|-----------|-----------|--------------|--------------|
| Langmuir  | K_L       | 0.070 ± 5.334E-4 | 0.599 ± 0.059 |
|           | Q_max     | 124.802 ± 0.693   | 117.909 ± 4.387 |
|           | Reduced Chi-Sqr | 0.166       | 2.976       |
|           | R-Square (COD)  | 0.998       | 0.998       |
|           | Adj. R-Square | 0.988       | 0.997       |
| Freundlich| K_f       | 9.271 ± 0.016   | 40.915 ± 3.722 |
|           | 1/n       | 0.776 ± 0.04348 | 0.480 ± 0.062 |
|           | Reduced Chi-Sqr | 0.1468     | 25.968      |
|           | R-Square (COD)  | 0.999       | 0.989       |
|           | Adj. R-Square | 0.999       | 0.979       |

Figure 7 | (a) Laguerre’s pseudo-first-order for BR18 adsorption, (b) pseudo-second-order for BR18 adsorption.

Figure 8 | (a) Laguerre’s pseudo-first-order for RBBR adsorption, (b) pseudo-second-order for RBBR adsorption.

Figure 9 | (a) 1/T vs ln K for BR18, (b) 1/T vs ln K for RBBR.
The results for multiplication of the universal gas constant were enthalpy changes for the adsorption of BR18 and RBBR. The enthalpies for the adsorptions of BR18 onto BR biomass and RBBR onto AA were 98.01 and 126.82 kJ/mol, respectively. Both of the adsorptions were exothermic since the changes in the enthalpy were negative. In contrast, the adsorption of malachite green onto lannea coromandelica was endothermic with a positive sign value for enthalpy (Mate et al. 2021). The change in the entropy was found by multiplying the line intercepts with the universal gas constant. The entropy changes for the removal of BR18 and RBBR were 312.37 and 399.21 J/mol.K, respectively. The negative signs of the entropy changes for both adsorptions indicate reductions in the randomness of the BR and AA surface at the end of the adsorption process (Dawood et al. 2017). In a previous study, the change in the entropy for the Congo red adsorption onto Eichhornia crassipes (BSEC) biomass was positive (Roy & Mondal 2019). The Gibbs free energy was calculated as shown in the equation. The Gibbs free energies for the adsorption of BR18 onto BR at temperatures of 298, 303, and 308 K were −4.29, −3.37, and −1.80 kJ/mol, respectively (Table 4). The Gibbs free energies for

![Figure 8](image_url)

**Figure 8** | (a) Lagergren’s pseudo-first-order for RBBR adsorption, (b) pseudo-second-order for RBBR adsorption.

**Table 3** | Lagergren’s pseudo-first-order and pseudo-second-order for the adsorption of BR18 and RBBR onto the BA and AA biomasses

| 1st Order Kinetic Model |  |  |  |  |  |  |
|-------------------------|---|---|---|---|---|---|
| Concentration (mg/L)   | 10 | 25 | 50 | 10 | 25 | 50 |
| k₁ (1/min)             | 0.476 ± 0.107 | 0.453 ± 0.098 | 0.459 ± 0.085 | 0.431 ± 0.022 | 0.331 ± 0.012 | 0.431 ± 0.098 |
| qₑ (mg/g)              | 8.578 ± 0.192 | 21.122 ± 0.489 | 40.837 ± 0.792 | 19.116 ± 0.113 | 47.628 ± 0.252 | 84.726 ± 2.193 |
| Reduced Chi-Sqr        | 0.146 | 0.941 | 2.474 | 0.050 | 0.243 | 18.878 |
| R-Square (COD)         | 0.990 | 0.998 | 0.992 | 0.999 | 0.999 | 0.987 |
| Adj. R-Square          | 0.988 | 0.987 | 0.991 | 0.999 | 0.999 | 0.984 |

| 2nd Order Kinetic Model |  |  |  |  |  |  |
|-------------------------|---|---|---|---|---|---|
| Concentration (mg/L)   | 10 | 25 | 50 | 10 | 25 | 50 |
| k₂ (g/mg.min)          | 0.146 ± 0.053 | 0.0553 ± 0.018 | 0.050 ± 0.009 | 0.065 ± 0.003 | NA | NA |
| qₑ (mg/g)              | 8.838 ± 0.186 | 21.822 ± 0.463 | 42.070 ± 0.713 | 19.615 ± 0.50 | 45.744 ± 1.840 | 82.737 ± 3.411 |
| Reduced Chi-Sqr        | 0.076 | 0.467 | 1.119 | 0.050 | 16.25 | 37.228 |
| R-Square (COD)         | 0.995 | 0.995 | 0.998 | 0.999 | 0.964 | 0.975 |
| Adj. R-Square          | 0.994 | 0.994 | 0.996 | 0.999 | 0.955 | 0.968 |
RBBR removal by AA were −7.86, −5.86, and −3.87 kJ/mol (Table 4). The adsorption processes were found to be feasible and spontaneous in nature for both dyes (Gibbs’s free energies are negative) (Biswas et al. 2020). The spontaneously occurring of bio sorption of cationic dyes was reported previously in many researches (Nethaji et al. 2013; Mittal et al. 2015). Also, the adsorptions of BR18 onto BR and RBBR onto AA were physisorption since the values of Gibbs free energy are lower than 20 kJ/mol (Hikmat et al. 2014). In addition to that, the lower temperatures were found to be more favorable since the Gibbs’ free energy values increased with temperature.

### 4. CONCLUSION

To sum up all the reported results, Russula brevipes and Agaricus Augustus were successfully fulfilled their role as sorbent biomass respectively for Basic Red (BR18) and Remazol Blue R (RBBR). In contrast, Fomes fomentarius did not present sorption efficiency. The Basic Red (BR18) was adsorbed thoroughly onto RB fungus with a removal efficiency of 90% (for a concentration of 10 mg/L). AA fungus was the best bio sorbent for Remazol Blue R (RBBR) removal (Removal efficiency reached 96% for a 10 mg/L concentration). The adsorption of BR18 onto RB biomass increased with the increases in the pH until pH 6. Beyond that (pH 6), the removal efficiency and the adsorption decreased with the increases in pH. For RBBR, the maximum efficiency and adsorption capacity were obtained at pH 2, and the pH increase reduced the removal efficiency and the adsorption capacity. The adsorption of BR 18 onto RB and the adsorption of RBBR onto AA can be considered fast processes. The removal efficiencies sharply increased after the first 5 min for both adsorbents. The adsorption of BR18 onto RB was described by Freundlich isotherms. Nevertheless, the Langmuir was the suitable isotherm for RBBR sorption onto AA. The kinetic study showed that the removal of BR18 sorption onto RB was shadowed by a pseudo-first-order model, while the RBBR sorption onto AA was followed by a pseudo-second-order model. Thermodynamic adsorption’s analysis approves that the sorption’s nature of the tested dyes is physisorption. Briefly, RB and AA biomass fungi showed promising performance for textile dye removal, which leads to use them as efficient bio, green, ecofriendly, and low-cost adsorbents.

### Table 4 | Thermodynamic parameter for the BR18 and RBBR

| T (°C) | BR18 | | RBBR | |
|-------|------|---|------|---|
|       | ΔH (kJ/mol) | ΔS (J/mol.K) | ΔG (kJ/mol) | ΔH (kJ/mol) | ΔS (J/mol.K) | ΔG (kJ/mol) |
| 25    | −98.01 | −312.37 | −4.93 | −126.82 | −599.21 | −7.86 |
| 30    | −83.77 | −272.78 | −3.37 | −106.15 | −555.55 | −5.86 |
| 35    | −83.77 | −212.55 | −1.80 | −96.42 | −511.11 | −3.87 |

RBBR removal by AA were −7.86, −5.86, and −3.87 kJ/mol (Table 4). The adsorption processes were found to be feasible and spontaneous in nature for both dyes (Gibbs’s free energies are negative) (Biswas et al. 2020). The spontaneously occurring of bio sorption of cationic dyes was reported previously in many researches (Nethaji et al. 2013; Mittal et al. 2015). Also, the adsorptions of BR18 onto BR and RBBR onto AA were physisorption since the values of Gibbs free energy are lower than 20 kJ/mol (Hikmat et al. 2014). In addition to that, the lower temperatures were found to be more favorable since the Gibbs’ free energy values increased with temperature.

### Figure 9

The relationship between normal logarithm of K and the inverse of temperature for (a) BR18 (b) RBBR.

### Table 4 | Thermodynamic parameter for the BR18 and RBBR

| T (°C) | ΔH (kJ/mol) | ΔS (J/mol.K) | ΔG (kJ/mol) | ΔH (kJ/mol) | ΔS (J/mol.K) | ΔG (kJ/mol) |
|-------|-------------|--------------|--------------|-------------|--------------|--------------|
| 25    | −98.01      | −312.37      | −4.93        | −126.82     | −599.21      | −7.86        |
| 30    | −83.77      | −272.78      | −3.37        | −106.15     | −555.55      | −5.86        |
| 35    | −83.77      | −212.55      | −1.80        | −96.42      | −511.11      | −3.87        |
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First received 3 November 2021; accepted in revised form 14 January 2022. Available online 29 January 2022.