Evaluation of Red Marine Alga Kappaphycus alvarezii as Biosorbent for Methylene Blue: Isotherm, Kinetic, and Mechanism Studies

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Evaluation of Red Marine Alga *Kappaphycus alvarezii* as Biosorbent for Methylene Blue: Isotherm, Kinetic, and Mechanism Studies

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In this work, non-living red seaweed (*Kappaphycus alvarezii*) biomass was investigated as a new biosorbent of methylene blue from aqueous solution. The effect of operational parameters such as equilibrium pH, agitation time, initial dye concentrations, and biosorbent dosage on the biosorption capacity of *Kappaphycus alvarezii* was studied. The equilibrium solution pH was found to profoundly affect methylene blue sorption capacity of *Kappaphycus alvarezii* with pH 8 found to be optimum. Evidence from Fourier-transform infrared spectroscopy and scanning electron microscopy pictures confirmed the dye biosorption mechanism as electrostatic interaction between the negatively charged seaweed surface and positively charged methylene blue. Biosorption isotherms indicated that *Kappaphycus alvarezii* exhibited methylene blue uptake of 74.4 mg/g, according to the Langmuir model. The equilibrium isotherm data were evaluated using the Freundlich, Langmuir, Redlich-Peterson, and Toth models. Kinetic studies revealed that methylene blue uptake was fast with 97% or more of the uptake occurred within 60 min of contact time. The pseudo first and second order models were applied to describe kinetic data, of which the pseudo-first order described experimental data better with high correlation coefficient and low percentage of error values.

**Keywords** seaweed; methylene blue; isotherm; kinetics; wastewater; biosorption

**INTRODUCTION**

Dyes are organic colorants used in several industries including textile, leather, food, and cosmetic. Wastewater discharged from these industries often comprises of residual dyes in various concentrations. The presence of dyes in the watercourse through effluents is aesthetically undesirable as well as leads to serious environmental impact (1). The release of dyestuffs into freshwater sources leads to a reduced dissolved oxygen concentration causing anoxic conditions, which eventually affect aerobic organisms (2). Various techniques have been employed for the treatment of dye containing wastewaters, including physiochemical and biological methods. Physiochemical methods include precipitation, chemical oxidation, membrane, and electrochemical technologies; however, they have few disadvantages such as being costly, not environmentally-friendly, and production of large amount of sludge (3, 4). Hence search for efficient, cheap, and eco-friendly methods for dye-bearing wastewaters are on the horizon.

In recent years, several biological methods have been identified to remediate dye wastewaters (5) of which, biosorption has been demonstrated to possess good potential to replace physiochemical methods for the removal of dyes (4). Biosorption is due to the ability of inactive/dead biological materials to bind toxicants through various mechanisms. The type of mechanism depends on the biosorbent itself and some of the removal mechanisms include ion-exchange, sorption, electrostatic attraction, complexation, and chelation.

Biosorbents such as bacteria, fungi, algae, and biological wastes from agriculture and industries were identified for effective removal of dyes (4, 6). Seaweed (marine algae) is a popular biosorbent for heavy metals; however, their efficiency in dye removal is often questionable. Seaweeds are biological resources, which are available in many parts of the world. Even though seaweeds have commercial importance, they are over generated in many instances and cause nuisance along seashores. Thus, its usage in pollutant removal is of interest and it may also add revenue to the local community. The studies associated with dye biosorption using marine algae are limited (7, 8, 9). In particular there is no research report using red marine algae for dye removal to our knowledge. *Kappaphycus alvarezii* is an important red alga and one of the most important commercial sources of carrageenans (10). It is also a
rapidly multiplying species with rigid macroscopic structure, thus particularly suitable for biosorption applications.

Thus the objective of the present research is to evaluate the biosorption capacity of *K. alvarezi* towards methylene blue from aqueous solution. Methylene blue was selected as the sorbate since it is one of the most important and widely used cationic dyes in the textile and paper industries. Initially, efforts were made to optimize the equilibrium pH, biosorbent dosage, contact time and dye concentration. The mechanism of dye biosorption was elucidated using SEM and FTIR results.

**MATERIALS AND METHODS**

**Preparation of Biosorbent and Chemicals**

The red seaweed, *K. alvarezi*, was collected from the beaches of Mandapam region, Tamilnadu, India. After collection, the seaweed samples were extensively washed with deionized water. After washing, the biomass was subsequently sun-dried and then grounded in a blender to prepare particles with average size of 0.75 mm for sorption experiments.

All chemicals used in this study were of analytical grade and purchased from Ranbaxy Fine Chemicals Ltd., India; whereas methylene blue was obtained from Sigma-Aldrich Corporation, Bangalore, India.

**Biosorption Experimental Procedure**

The pH of the methylene blue solution was initially adjusted using 0.1 M HCl or 0.1 M NaOH. In all experiments, 0.5 g of *K. alvarezi* biomass was contacted with 100 mL of dye solution in 250 mL Erlenmeyer flasks. The contents were then agitated in an incubated rotary shaker at 150 rpm for 2 h at 30°C. Once equilibrium was reached, samples were centrifuged at 3500 rpm for 5 min, and the supernatant liquid was analyzed in a spectrophotometer (UV-1800, Shimadzu, Japan) at 665 nm. The amount of dye biosorbed was calculated from the difference between the dye quantity initially added to the seaweed biomass and the dye content of the supernatant using the following equation:

\[ Q = V \times (C_0 - C_f)/M \]  

where *Q* is the dye uptake (mg/g); *C₀* and *Cᵢ* are the initial and final dye concentrations in the solution (mg/L), respectively; *V* is the volume of dye solution (L); and *M* is the mass of biosorbent (g). For pH edge experiments, initial methylene blue concentration was fixed at 100 mg/L and pH was varied from 5-9. In the case of isotherm experiments, initial methylene blue concentrations were varied from 25-300 mg/L. The kinetic experiments were also conducted with methylene blue concentrations in the range of 25-300 mg/L and samples were withdrawn at specific time intervals.

**Characterization of *K. alvarezi***

The seaweed samples before and after sorption were characterized using FTIR and SEM analysis. For FTIR sampling, a sample of *K. alvarezi* before and after methylene blue sorption was dried and coated with KBr to form pellets and analyzed using FTIR-spectrometer ATR IR with 4 cm⁻¹ resolution for crystal-ZnSe scan range of 600 to 4000 cm⁻¹. At particular wavelengths, the basic structure of compounds can be determined by the spectral locations of their IR absorptions.

To understand the surface morphology and sorption removal mechanism of seaweed, the samples before and after adsorption of methylene blue were dried, coated with a thin layer of gold, and analyzed by SEM (Hitachi S4800 EDX).

**Isotherm and Kinetic Modeling**

Four equilibrium isotherm models were used to describe the methylene blue biosorption data as follows:

- **Freundlich model:**
  \[ Q = K_F C_f^{1/n_F} \]  

- **Langmuir model:**
  \[ Q = \frac{Q_{\text{max}} b C_f}{1 + b C_f} \]  

- **Redlich-Peterson model:**
  \[ Q = \frac{K_{\text{RP}} C_{eq}}{1 + a_{\text{RP}} C_{eq}^{b_{\text{RP}}}} \]  

- **Toth model:**
  \[ Q = \frac{Q_{\text{max}} b_T C_f}{[1 + (b_T C_f)^{1/n_T}]^{n_T}} \]

where \( Q_{\text{max}} \) is the maximum methylene blue uptake (mg/g), \( b \) is the Langmuir equilibrium constant (L/mg), \( K_F \) is the Freundlich constant (mg/g) (L/mg)^{1/n_F}, \( n_F \) is the Freundlich exponent, \( K_{\text{RP}} \) is the Redlich-Peterson isotherm constant (L/g), \( a_{\text{RP}} \) is the Redlich-Peterson isotherm constant (L/mg)^{1/b_{\text{RP}}}, \( b_{\text{RP}} \) is the Redlich-Peterson model exponent, \( b_T \) is the Toth model constant (L/mg), and \( n_T \) is the Toth model exponent.

Two kinetic models were used to describe the experimental data, as follows:

- **Pseudo-first order model:**
  \[ Q_t = Q_e (1 - \exp(-k_1 t)) \]  

- **Pseudo-second order model:**
  \[ Q_t = \frac{Q_{\text{e}}^2 k_2 t}{1 + Q_{\text{e}} k_2 t} \]  

where \( Q_e \) is the amount of methylene blue sorbed at equilibrium (mg/g), \( Q_t \) is the amount of methylene blue sorbed at time \( t \) (mg/g), \( k_1 \) is the pseudo-first order rate constant (L/min), and \( k_2 \) is the pseudo-second order rate constant (g/mg.min). All the model parameters were evaluated by non-linear regression using Sigma Plot (version 4.0, SPSS, USA) software.
The average percentage error between the experimental and the predicted values was calculated using,

\[
\% \text{ Error} = \frac{\sum_{i=1}^{N} (Q_{\text{exp},i} - Q_{\text{cal},i}/Q_{\text{exp},i})}{N} \times 100
\]  

where \(Q_{\text{exp}}\) and \(Q_{\text{cal}}\) represent the experimental and calculated uptake values, respectively, and \(N\) is the number of measurements.

RESULTS AND DISCUSSION

Effect of pH

The interaction between a dye molecule and an adsorbent is generally as a result of overall charge of the adsorbent surface and that of dye molecule (11, 12). The solution pH is an important parameter influencing the overall charges and thus decides the sorption behavior of solute onto the surface of biosorbent (4, 13). In the present study, the effect of pH on biosorption of methylene blue by \(K.\ alvarezi\) was studied over a pH range of 5-9. The minimum and maximum percentage (46 % and 92%) of dye adsorbed at pH 5 and 8 as shown in Fig. 1, the uptake of methylene blue by \(K.\ alvarezi\) was severely affected by equilibrium pH. The uptake increased with an increase in pH and reached maximum at pH 8 and further increase in pH resulted in decreased methylene blue uptake. The functional groups present on the cell wall of red algae (hydroxyl and carboxyl) usually confer an overall negative charge to the cell surface (14). On the other hand, basic dyes release colored and positively charged dye ions in solution, which are electrostatically attracted towards the negatively charged algal surface. At slightly acidic pH values, the negatively charged groups of \(K.\ alvarezi\) will be protonated which gives the biomass an overall positive charge. Under this scenario, the binding of methylene blue onto seaweed biomass will be different and hence low uptake was observed.

Influence of Seaweed Dosage on Methylene Blue Removal

The effect of \(K.\ alvarezi\) dosage on methylene blue biosorption was studied by varying dosages from 2 to 6 g/L with optimized pH 8 and initial concentration 100 mg/L. The results revealed that the methylene blue removal efficiency increases with increase in seaweed dosage. An increase in biomass concentration generally increases the biosorbed dye molecules because of an increase in surface area of the biosorbent, which in turn increases the binding sites (15). For instance, 94% methylene blue removal recorded for 2 g/L seaweed dosage increased to 97% for 5 g/L and then decreased to 95% for 6 g/L. On the other hand, the dye uptake decreases by increasing the biosorbent dosage. This may be due to complex interactions of several factors, the main factor being at high seaweed dosages the available dye molecules are insufficient to cover all the exchangeable sites on the seaweed surface, usually resulting in low dye uptake. Also, the interference between binding sites due to increased sorbent dosages will result in low dye uptake (16). In the present study, 4.75 mg/g observed at 2 g/L seaweed dosage increased to 19.4 mg/g at 5 g/L. Few authors observed this trend (15, 17). Thus, analyzing the results, 5 g/L seaweed dosage was selected as optimum as it exhibited highest methylene blue removal efficiency.

Mechanism Studies

For a detailed understanding on the intensity and nature of functional groups on the biomass surface, FTIR spectra of raw and methylene blue biosorbed \(K.\ alvarezi\) were analyzed. The well-resolved FTIR spectra with strong absorptions at 922.06 and 842.68 cm\(^{-1}\) as expected for \(j\)-carrageenan present in the \(K.\ alvarezi\). It also revealed the spectra of the seaweed which showed the main features of kappa-carrageenan: a band at approximately 699.88 cm\(^{-1}\) with moderate intensity, which is assigned to D-galactose-4-sulphate (G4S) and a relatively strong band at approximately 1030.20 cm\(^{-1}\) in the FTIR spectra, weak spectrum, indicating the presence of 3, 6-anhydro-D-galactose (DA) polymeric nature of compounds along with the presence of hydroxyl, ketonic, acidic, and ester functional groups. Such groups are capable of reacting with the functional groups of dye molecules.

The FTIR spectrum of powdered material (Fig. 2a) showed a broad peak at 3340.67 to 2901.74 cm\(^{-1}\), indicates the presence of N-H groups and also the vibrational of the –OH group. The peak at 1643.00 cm\(^{-1}\) is attributed to stretching of conjugated carbonyl bond in the lignin (18, 19). The other bands around 1602.30 cm\(^{-1}\) to 1643.00 cm\(^{-1}\) are attributed to aromatic rings, aromatic skeletal vibrations, and aromatic ring deformation. The spectra of control also show the bands at approximately 921 and 643.40 cm\(^{-1}\), with the same intensity pattern as in kappa-carrageenan, also shows the presence of high sulphate content. The FTIR spectrum displays the characteristic peaks of the compound of sea weed \(K.\ alvarezi\) treated with methylene blue experiment (Fig. 2b). The peak at

![FIG. 1. Influence of pH and \(K.\ alvarezi\) on MB removal efficiency.](https://example.com/fig1.jpg)
The surface morphology and sorption of methylene blue in the surface microstructures of red seaweed (*K. alvarezii*) was further observed by SEM. The control red seaweed (*K. alvarezii*) appears as thick cell wall and surface protuberance could be observed with dense leathery appearance with irregular rough surface (Fig. 3a). Considerable amount of methylene blue was found to sorb to the surface of red seaweed (*K. alvarezii*), which might be due to electrostatic interaction of methylene blue molecules with negatively charged groups of biomass, and thus the surface appears flat and pores can no longer be seen on the surface of the *K. alvarezii* (Fig. 3b) (20).

Thus, SEM images coincided with the dye biosorption mechanism as electrostatic interaction between the negatively charged seaweed surface and positively charged methylene blue cations. This shows that the dye adhered to the surface *K. alvarezii*.

**Biosorption Kinetics and Modeling**

The prediction of batch biosorption kinetics is necessary to understand the reaction pathways and the mechanism of a sorption reaction, which in turn are necessary for design of industrial sorption treatment columns. Figure 4 illustrates the plot of methylene blue uptake versus contact time at different initial methylene blue concentrations at pH 8. At all concentrations examined, the complete biosorption equilibrium was attained within 60 min. The rapid kinetics observed with *K. alvarezii* represents a significant advantage for its application in wastewater scheme. It was also inferred that increase in methylene blue concentration increased the uptake capacity of seaweed biomass. Initial dye concentration provides an important driving force to overcome all mass transfer resistances of the dye between the aqueous and solid phases; thus increase in initial concentration usually enhances dye removal (9). However, this is not the case when % dye removal efficiency
was considered. For instance, on increasing methylene blue concentration from 25 to 300 mg/L, the dye uptake increased from 4.75 to 54.0 mg/g; however, the % removal decreased from 95 to 90 on increasing methylene blue concentration from 150 to 300 mg/L. This is because at lower concentrations, the moles of dye to the available surface area of the sorbent are low which causes the fractional sorption to become independent of the initial concentration. However, at higher concentrations the available sorption binding sites are decreased compared to the moles of dye present and hence the dye percentage removal is depends upon the initial dye concentration.

The experimental kinetics data were modeled using pseudo-first and second order models. Table 1 shows the model constants along with correlation coefficient ($R^2$) and % error values obtained at different methylene blue concentrations. In the case of pseudo-first order model, $R^2$ values were above 0.94 and % error values less than 13.2% at all concentrations examined. The model was able to predict uptake values reasonably close to that of experimental values (Table 1). On the contrary, the pseudo-second order model over-predicted methylene blue uptake values. Usually, the pseudo-second order model predicts the sorption behavior over the whole range of studies and it is in agreement with a chemisorption mechanism being the rate controlling step. However, several authors observed the tendency of the model to over predict the equilibrium uptake values (21, 22). The rate constant ($k_2$) decreased with increasing initial methylene blue concentrations. The curves as predicted by both pseudo-first and second order models are presented in Fig. 4.

**Biosorption Isotherm and Modeling**

The quality of a biosorbent is usually judged by how much pollutant it can bind and retain in an immobilized form. To evaluate the full potential of *K. alvarezii* in methylene blue removal, which is useful in the biosorption isotherm curve which is a plot of equilibrium methylene blue concentration versus methylene blue uptake by *K. alvarezii*. Isotherms were evaluated by varying initial methylene blue concentrations in the range of 25-300 mg/L at pH 8. An isotherm of L-shape without strict plateau was observed (Fig. 5). This means that the ratio between the concentration of dye molecules remaining in solution and biosorbed on the seaweed surface decreases when the solute concentration increases, providing a concave curve (23). From this study, the maximum experimental uptake was observed as 54.0 mg/g whereas the maximum theoretical uptake was

![FIG. 4. Biosorption kinetics of *K. alvarezii* towards MB (pH 8).](image)

<table>
<thead>
<tr>
<th>Initial dye concentration (mg/L)</th>
<th>$Q_e$ (mg/g)</th>
<th>$k_1$ (l/min)</th>
<th>$Q_t$ (mg/g)</th>
<th>$R^2$</th>
<th>% Error</th>
<th>$k_2$ (l/min)</th>
<th>$Q_t$ (mg/g)</th>
<th>$R^2$</th>
<th>% Error</th>
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<tbody>
<tr>
<td>25</td>
<td>4.8</td>
<td>0.019</td>
<td>5.7</td>
<td>0.951</td>
<td>13.1</td>
<td>0.0016</td>
<td>8.5</td>
<td>0.941</td>
<td>12.5</td>
</tr>
<tr>
<td>50</td>
<td>9.6</td>
<td>0.020</td>
<td>11.4</td>
<td>0.956</td>
<td>10.1</td>
<td>0.0009</td>
<td>16.5</td>
<td>0.944</td>
<td>11.2</td>
</tr>
<tr>
<td>100</td>
<td>19.4</td>
<td>0.027</td>
<td>21.9</td>
<td>0.944</td>
<td>7.8</td>
<td>0.0007</td>
<td>29.8</td>
<td>0.925</td>
<td>5.0</td>
</tr>
<tr>
<td>150</td>
<td>28.5</td>
<td>0.023</td>
<td>32.8</td>
<td>0.956</td>
<td>10.7</td>
<td>0.0004</td>
<td>46.6</td>
<td>0.942</td>
<td>14.8</td>
</tr>
<tr>
<td>200</td>
<td>37.6</td>
<td>0.020</td>
<td>42.0</td>
<td>0.986</td>
<td>8.2</td>
<td>0.0003</td>
<td>60.4</td>
<td>0.979</td>
<td>21.1</td>
</tr>
<tr>
<td>300</td>
<td>54.0</td>
<td>0.019</td>
<td>63.1</td>
<td>0.981</td>
<td>3.6</td>
<td>0.0002</td>
<td>91.1</td>
<td>0.974</td>
<td>0.14</td>
</tr>
</tbody>
</table>

![FIG. 5. Biosorption isotherm of MB (pH 8).](image)
recorded as 75.7 mg/g based on the Toth isotherm whose slope was found to be steep. In general, the steep slope represents higher affinity of the sorbate toward the sorbent (4).

Isotherm pertaining to the biosorption of methylene blue onto *K. alvarezi* was tested using the two-parameter (Freundlich and Langmuir) and three-parameter (Redlich-Peterson and Toth) models. The Freundlich model is an empirical equation based on an exponential distribution of sorption sites and energies. It also assumes that the stronger binding sites are occupied first and that the binding strength decreases with the increasing degree of site occupation. Relatively low \( R^2 \) (0.963) and high % error (20.22%) were obtained. The binding capacity constant \((K_F)\) and constant associated with affinity of sorbent and sorbate \((n_F)\) were determined as 8.98 (mg/g) \((L/mg)^{1/n} \) and 1.86, respectively. The classical Langmuir model incorporates two easily interpretable constants: \( Q_{max} \), which corresponds to the maximum achievable uptake by a system; and \( b \), which is related to the affinity between the sorbate and sorbent. The Langmuir model was originally developed to describe the gas-solid phase adsorption of activated carbon. Later, the model was successfully used to quantify and contrast the performance of different adsorbents and biosorbents (4). In its formulation, the Langmuir model assumes binding to the surface was primarily by physical forces and all sites possess equal affinity for the sorbate. The model constants, \( Q_{max} \) and \( b \), were recorded as 74.4 mg/g and 0.087 L/mg, respectively with \( R^2 \) and % error values of 0.989 and 8.62%, respectively. Efforts were also made to compare the methylene blue biosorption performance of *K. alvarezi* with other biomasses reported in the literature (Table 2). Results revealed that *K. alvarezi* performed comparatively better than most of other biosorbents.

The application of the three-parameter model drastically improved the fitness of methylene blue biosorption isotherm. The Redlich-Peterson model is a combination of the Langmuir and Henry’s model. The model incorporates three parameters (\( K_{RP}, a_{RP} \) and \( \beta_{RP} \)) into an empirical isotherm, and thus can be applied to either homogenous or heterogeneous systems. When \( \beta_{RP} = 0 \), the model reduces to the Langmuir model, while when \( \beta_{RP} = 1 \), the model transforms to Henry’s law form. For the present system, \( \beta_{RP} \) was estimated as 0.97 which indicates that methylene blue isotherm data were more of the Langmuir form. The other constants, \( K_{RP} \) and \( a_{RP} \), were estimated as 6.65 L/g and 0.099 (L/mg)^{1/\beta_{RP}}, respectively. The Redlich-Peterson model resulted in better \( R^2 \) (0.989) and low % error (7.42%) values. Further, the Toth model was examined for its compatibility with the methylene blue isotherm data. Very high \( R^2 \) (0.989) and low % error (8.84%) values were obtained for the Toth isotherm. The Toth model derived from potential theory has proven useful in describing sorption in heterogeneous systems. It assumes an asymmetrical quasi-Gaussian energy distribution with a widened left-hand side, i.e. most sites have sorption energy less than the mean value (24). The Toth model constants, \( Q_{max}, b_{T} \), and \( n_T \) were recorded as 75.7 mg/g, 0.087 L/mg, and 1.03, respectively.

### TABLE 2

<table>
<thead>
<tr>
<th>Adsorbent</th>
<th>Uptake (mg/g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banana peel</td>
<td>20.8</td>
<td>(25)</td>
</tr>
<tr>
<td>Orange peel</td>
<td>18.6</td>
<td>(25)</td>
</tr>
<tr>
<td>Fly ash</td>
<td>13.4</td>
<td>(26)</td>
</tr>
<tr>
<td>Neem leaf powder</td>
<td>8.76—19.6</td>
<td>(27)</td>
</tr>
<tr>
<td>Rice husk</td>
<td>40.5</td>
<td>(28)</td>
</tr>
<tr>
<td>Wheat shells</td>
<td>16.6—21.5</td>
<td>(29)</td>
</tr>
<tr>
<td><em>Posidonia oceanica</em> fibres</td>
<td>5.56</td>
<td>(30)</td>
</tr>
<tr>
<td><em>Paspalum notatum</em></td>
<td>30.4—31.4</td>
<td>(31)</td>
</tr>
<tr>
<td><em>Caulerpa racemosa var. cylindracea</em></td>
<td>3.4</td>
<td>(8)</td>
</tr>
<tr>
<td><em>Nuchar WWH</em></td>
<td>21.5</td>
<td>(32)</td>
</tr>
<tr>
<td><em>C. barbutula</em></td>
<td>38.6</td>
<td>(33)</td>
</tr>
<tr>
<td>Coffee press cake</td>
<td>14.9</td>
<td>(34)</td>
</tr>
<tr>
<td>Date Stones</td>
<td>43.5</td>
<td>(35)</td>
</tr>
<tr>
<td>Palm-Tree waste</td>
<td>39.5</td>
<td>(35)</td>
</tr>
<tr>
<td><em>Rapana Venosa</em> gastropod</td>
<td>16.8</td>
<td>(36)</td>
</tr>
<tr>
<td>Wheat bran</td>
<td>25.2</td>
<td>(37)</td>
</tr>
<tr>
<td><em>Kappaphycus alvarezi</em></td>
<td>74.4</td>
<td>This study</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

This paper examined the biosorption of methylene blue by red marine alga *K. alvarezi*. The main results obtained can be summarized as below:

- The biosorption capacities were solution pH dependent and optimum pH was found to be 8 for methylene blue removal by *K. alvarezi*.
- Biosorption isotherm was modeled using the Freundlich, Langmuir, Redlich-Peterson and Toth models. The seaweed biomass exhibited methylene blue uptake of 74.4 mg/g, based on the Langmuir model. Based on correlation coefficients and % error values, the Toth model better described methylene blue isotherm data.
- Of the different biosorbent dosage examined, 5 g/L seaweed dosage was selected as optimum as it exhibited highest methylene blue removal efficiency (97%) and high uptake.
- The kinetics of biosorption was found to be rapid and the data obtained at different methylene blue concentrations were modeled effectively by the pseudo-first order model in comparison with pseudo-second order model.
- Considering the results obtained from the present study, it can be concluded that *K. alvarezi* would be well suited for removal of methylene blue-bearing wastewaters.
REFERENCES