Fast removal of methylene blue from aqueous solution using porous soy protein isolate based composite beads

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HIGHLIGHTS

- We reported a novel porous composite adsorbent.
- High adsorption capacity and fast adsorption of MB by the adsorbent are achieved.
- Maximum sorption capacity for MB by the adsorbent was 272.4 mg g⁻¹.
- The adsorption of MB onto the adsorbent was exothermic and spontaneous.

GRAPHICAL ABSTRACT

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ABSTRACT

Soy protein isolate (abbreviated as SPI) was chemically immobilized on deacetylated konjac glucomannan (abbreviated as DKGM) in the current work. The obtained porous SPI/DKGM composite beads were characterized by scanning electron microscopy (SEM), Fourier transform infrared spectra (FTIR) and zeta potential analysis. Adsorption performances of porous SPI/DKGM composite beads were tested to remove methylene blue from aqueous solution. Benefiting from the combined merits of SPI, high adsorption capacity and fast adsorption of methylene blue (MB) by porous SPI/DKGM composite beads are achieved. The maximum methylene blue adsorption capacities were shown to be 272.4 mg g⁻¹ for porous SPI–DKGM composite beads. These results confirm that the porous SPI–DKGM composite beads have a potential for methylene blue removal from wastewater.

1. Introduction

Freshwater contamination with dyestuff is becoming a great environmental problem. Dyes are widely used in various industries, such as textile, paper, leather tanning, paint, printing and cosmetics [1]. The increasing industrial growth is the major source of dyestuff introduction into freshwater. Most dyes are complex organic molecules and chemically synthesized. They can be classified into three major types as anionic, cationic and non-ionic disperse dyes. Methylene blue (MB) as a type of cationic dyes is widely used in many fields such as dyeing, monitoring and printing. MB discharges into freshwater give undesirable color to hydrosphere which may reduce sunlight penetration and affect photosynthetic activity in aquatic life. MB hazardous effects can cause health problems, such as skin irritation, increased heart rate on inhalation and cancer [2].

Commonly accepted technologies for the removal of MB from wastewater include adsorption [3], photocatalytic oxidation [4], photocatalytic degradation [5,6] and membrane separation treatment [7,8]. Each technology has its own advantages and disadvantages. Adsorption has been found to be superior to other techniques in terms of low cost, simplicity of design and ease of operation. There has been increased focus on developing new
adsorbents with high adsorption capabilities for MB removal from wastewater stream, such as graphene oxide [9–11], nanotubes [12], nanocomposite [13,14], activated carbon [15–17], metal oxide [18–20], biosorbents [21–23]. Moreover, composite adsorbents are emerging as a new generation of adsorbent for dye removal because the inherited disadvantages of the individual adsorbents might be minimized by combining them [24–27].

Soy protein isolate (SPI) extracted from Soybean is currently one of the most abundant sources of plant proteins. The major components of SPI are of Glycinin (7S) and β-conglycinin (11S), in which there consist of 20 different amino acids, such as aspartic, lysine, phenylalanine, leucine, glutamic acid and tyrosine [28]. SPI in which there consist of 20 different amino acids, such as aspartic, lysine, phenylalanine, leucine, glutamic acid and tyrosine [28]. SPI with good metal-chelating properties has a significant potential as a biosorbent for removal of heavy metals from wastewater [33]. Although SPI shows great potential as adsorbent, it suffers from drawbacks such as high solubility in acidic solutions or basic solution and inadequate mechanical properties [29,34].

Konjac glucomannan (KGM), a natural polysaccharide derived from the tubers of Amorphophallus konjac, consists of a-mannose and d-glucose in a molar ratio of 1.6:1 with a β-1,4-linkage and contains acetyl group per every 12 or 18 repeating units [35,36]. The most important feature of KGM lies on acetyl groups on KGM. Hydrogels of KGM with cross-linked network are formed after deacetylation in alkaline condition [37]. Hydrogels of KGM containing various functionalities and porosities are stable in most organic solvents, allowing them also to be suitable for environmental applications [38].

Hydrogels of deacetylated konjac glucomannan (DKGM) with three-dimensional crosslinked networks are able to absorb and retain water soluble SPI biomacromolecules. SPI biomacromolecules can further be immobilized onto DKGM using cross-linking agents. As hydrogels of DKGM possess amine functional groups, they can absorb cationic dyes such as MB. In the present work, we aim to design porous SPI/DKGM composite beads as an efficient composite adsorbent for dye removal. Hydrogel of DKGM with supramolecular architectures endows it with porosities to use as an immobilization matrix for SPI impregnation. The adsorption of MB onto porous SPI/DKGM composite beads, including effects of pH, dosage, contact time, temperature and initial MB concentration, was systematically investigated by batch adsorption experiments. We also thoroughly studied the kinetics, isotherms and thermodynamics of adsorption process.

2. Experimental

2.1. Materials

Refined KGM powders were purchased from Mianyang Anxian Dule Company and were used without further purification. SPI powders containing 88% protein (dry basis) were purchased from Shanghai Jiaoyuan Industrial Co., Ltd and were used without further purification. All other chemicals (epichlorohydrin, isopropanol, alcohol, sodium hydroxide, hydrochloric acid, methylene blue, etc.) used in this work were all of analytical grade and obtained from Aladdin Reagent of China.

2.2. Preparation of DKGM

DKGM was synthesized following a modified literature method [39]. KGM flour (20.0 g) and sodium hydroxide (0.35 g) were dispersed in 120 mL alcohol/water mixture solution (50:70 V/V) in a three-necked round-bottomed flask (250 mL) equipped with a mechanical stirrer. The reaction mixture was stirred (400 rpm) at 50 °C for 12 h. The obtained product was filtered out and washed with distilled water, and then dried under vacuum for 48 h, yielding 18.8 g of the product as white powders in a 94% yield.

2.3. Preparation of SPI/DKGM composite beads

SPI (8.0 g), sodium hydroxide (8.0 g) and distilled water (40.0 mL) were mixed and stirred mechanically at 60 °C for 30 min in a three-necked round-bottomed flask (500 mL). This was followed by the addition of 8.0 g of DKGM. The mixture was stirred at 60 °C for 2 h. Under mechanical stirring at 400 rpm, 400.0 mL of isopropanol was added into the flask. Subsequently, 12.0 mL of epichlorohydrin was introduced into the flask using a syringe. The cross-linking reaction was allowed to proceed for 15 h. After 15 h, SPI/DKGM composite beads was filtered out of reacted system and washed thoroughly with distilled water in order to remove free SPI that may be attached to the surface of DKGM powder. The product was dried to a constant weight (10.8 g) at 100 °C.

2.4. Characterization

The micrographs of SPI, DKGM and SPI/DKGM composite beads were observed by a HITACHI-SUB010 scanning electron microscopy (SEM).

A Nicolet -6700 model FT-IR spectrometer was used to record FTIR spectra for functional group analysis of the natural DKGM, SPI, SPI/DKGM composite beads, MB absorbed SPI/DKGM composite beads and MB samples.

Zeta potentials of SPI/DKGM composite beads were determined by a Nano-ZS Zetasizer (Malvern, UK) following the literature method [38]. Dry SPI/DKGM composite beads (0.25 g) were added in KNO₃ solution (50 cm³, 1.0 M). The pH of the mixture was adjusted between 2.0 and 8.0, using potassium hydroxide (0.10 M) or hydrochloric acid (0.10 M). The mixture was magnetically stirred for 30 min. The supernatant was collected via transfer pipetting for zeta potential measurements.

A Shimadzu UV-2550 spectrophotometer was used to determine the concentrations of MB left in supernatant solutions referring to the standard curve of MB at the maximum wavelength (665 nm) of MB dye.

Water absorbencies of DKGM and SPI/DKGM composite beads were determined following the literature method [38].

The protein content of dried SPI/DKGM composite beads samples was measured by the micro-Kjeldahl method and nitrogen to protein conversion factor of 6.25 was used for calculation following the literature method [40].

2.5. Bath experiments

The samples of SPI/DKGM composite beads were used for adsorption study regarding the effects of initial pH, adsorbent dosage, contact time, temperature and initial MB concentration. All of the following adsorption experiments were done in triplicate in a 250 mL stopped conical flask containing 50.0 mL of MB solution. Initial MB solutions with different concentrations were prepared by proper dilution from stock MB standards (1000 mg L⁻¹). The pH of initial MB solution was adjusted by sodium hydroxide (0.10 M) and hydrochloric acid (0.10 M). A certain amount of the adsorbent was added and the mixture in the flask was shaken for a predetermined contact time on a platform constant shaking incubator at 200 rpm. Samples were taken and filtered, and the MB concentrations of the filtrates were measured by a Shimadzu
UV–2550 spectrophotometer. The average of the three residual MB concentrations in the filtrates was used in the analysis. The uptake capacity \( q_e \) and removal efficiency \( E(\%) \) of adsorbent were calculated as follows:

\[
q_e(\text{mg/g}) = \frac{(C_0 - C_e)V}{1000w}
\]

\[
E(\%) = \frac{C_0 - C_e}{C_0} \times 100
\]

where, \( C_0 \) (mg L\(^{-1}\)) and \( C_e \) (mg L\(^{-1}\)) are the initial MB concentration and MB concentration after adsorption, respectively. \( V \) is the volume of the solution in mL and \( w \) is the weight of the adsorbent in g.

2.6. Regenerated experiments

Desorption of the adsorbed MB from SPI/DKGM composite beads was studied by static experiment. SPI/DKGM composite beads (0.30 g) was added into 500 mL stoppered conical flask containing 300 mL of 600 mg L\(^{-1}\) MB solution and the mixture in the flask was shaken at 25 °C for 30 min. The MB adsorbed SPI/DKGM composite beads was filtered out and placed in the 250 mL stoppered conical flask containing 200 mL of 0.01 M hydrochloric acid for desorption, and stirred continuously at 25 °C for 60 min. The final MB concentration in the filtrate and desorptive solvent was detected. The adsorption–desorption process was repeated 4 times using the same adsorbent.

3. Results and discussion

3.1. Synthesis and characterization of SPI/DKGM composite beads

The synthetic route to the SPI/DKGM composite beads is illustrated in Scheme 1. Before DKGM powders were added into the flask, SPI powders were dissolved in NaOH solution with light yellow color. DKGM has certain swelling degree in aqueous solution with water absorbency of 4.8 g g\(^{-1}\). In an example preparation, SPI (8.0 g) was dissolved in water (40 mL). DKGM powders (8.0 g) can provide ~40 mL free volume to accommodate SPI solution. SPI solution (~40 mL) was adsorbed on DKGM (8.0 g). The SPI/DKGM composite beads were further dispersed in isopropanol and were crosslinked by epichlorohydrin. The yellow SPI/DKGM composite beads were filtered out and washed thoroughly with distilled water in order to remove unfixed SPI. The protein content of dried SPI/DKGM composite beads was 24.23% measured by the micro-Kjeldahl method.

In order to gain insight into the structural information of SPI/DKGM composite beads, the morphologies of SPI, DKGM and SPI/DKGM composite beads were observed by SEM. Fig. 1 shows the scanning electron micrographs of SPI (×1000), DKGM (×100), SPI/DKGM composite beads (×100, ×250). The scanning electron micrographs of SPI and DKGM powders showed capsular structure and irregular granular structure with the size of 10–50 μm and 150–350 μm, respectively. The morphology of DKGM has become shrunken and wrinkled because of water loss. The micrograph of SPI/DKGM composite beads showed a difference in morphology from SPI and DKGM. After SPI immobilized on DKGM, SPI/DKGM composite beads with the size of 200–500 μm exhibited obvious porous structure with very coarse surfaces. Free volume of DKGM in the molecular structure was occupied and stuffed by SPI. By carefully weighing the DKGM samples before and after SPI modification, a significant increase of 35 wt% was recorded due to the SPI adsorption. Unfixed SPI of 65 wt% as a porogen was redissolved in water by washing treatment. The water absorbency of SPI/DKGM composite beads was 2.0 g g\(^{-1}\). The following loss of free SPI and the adsorbed water by washing and drying treatment led to form numerous pores in the SPI/DKGM composite beads.

Fig. 2(a–e) shows the FTIR spectra of the DKGM, SPI, SPI/DKGM composite beads, MB adsorbed SPI/DKGM composite beads and MB samples, respectively. For the DKGM (Fig. 2a), the broad band at 3381 cm\(^{-1}\) contributes to the stretching vibration of the O–H groups. The absorption band at 1650 cm\(^{-1}\) is corresponding to the C–O intra-molecular hydrogen bonds [41]. The band at 1083 cm\(^{-1}\) is resulted from bridge O stretch [42]. The peaks at 983 and 849 cm\(^{-1}\) are the characteristic absorption bands of mannoside residues in the polysaccharides [43]. For the SPI (Fig. 2b), absorption bands associated with amide groups in SPI structure are observed at 1650 cm\(^{-1}\), 1540 cm\(^{-1}\) and 1238 cm\(^{-1}\), which can be attributed to amide I band, amide II band and amide III band [30]. Compared with spectra of DKGM and SPI, all characteristic peaks of SPI were appeared in the spectrum of SPI/DKGM composite beads (Fig. 2c). The successful immobilization of SPI onto DKGM was confirmed by FTIR. It is apparent that these bands shown in Fig. 2c are accompanied by an increase in the absorption.

![Scheme 1. Synthetic route to the SPI/DKGM composite beads.](image-url)
at 1142 cm\(^{-1}\) and 1033 cm\(^{-1}\) corresponding to C–N stretch and C–O stretch, respectively. The C–N stretching peak overlaps the C–O stretching peak. The C–O stretching band increase can validate the crosslinking reaction between epichlorohydrin and the hydroxyl groups of DKGM [23]. On the other hand, the C–N stretching band increase can reflect the evidence for the crosslinking reaction between epichlorohydrin and the amine groups of SPI. Compared with spectra of SPI/DKGM composite beads and MB in Fig. 2(c, e), three peaks at 1600 cm\(^{-1}\) and 1390 cm\(^{-1}\) and 1340 cm\(^{-1}\) shown in the spectrum of MB adsorbed onto SPI/DKGM composite beads (Fig. 2d) were recognized as MB with the aromatic ring vibration, the C–N stretching vibrations and the CH\(_3\) group vibrations, respectively [12]. It is the evidence for adsorption between MB and SPI/DKGM composite beads.

3.2. Effects of initial pH value and Zeta potential analysis

The effects of the initial solution pH value on the adsorption of MB on SPI/DKGM composite beads and Zeta potential of SPI/DKGM composite beads are shown in Fig. 3. The MB adsorption capacity of SPI/DKGM composite beads increased with increasing initial solution pH from 2 to 8 shown in Fig. 3a. It was found that maximum adsorption capacity was achieved for MB at pH 6.0. SPI/DKGM composite beads showed a maximum adsorption capacity of 122.4 mg g\(^{-1}\). Zeta potential analysis was conducted in order to determine the surface charge on the SPI/DKGM composite beads shown in Fig. 3b. A charge reversal is observed for SPI/DKGM composite beads. \(p_H ZPC\) (zero-point charge of pH) of SPI/DKGM composite beads is \(\sim 4.4\). At low pH (pH < \(p_H ZPC\)), MB adsorption capacity of SPI/DKGM composite beads is lower than 45.0 mg g\(^{-1}\). The reason may be attributed to electrostatic repulsion between positively charged SPI/DKGM composite beads and positively charged MB. At high pH (pH > \(p_H ZPC\)), the SPI/DKGM composite beads sample surfaces become negatively charged and they favor the adsorption of positively charged MB [44].

3.3. Effects of adsorbent dosage

Effects of DKGM and SPI/DKGM composite beads dosage on removal efficiency were investigated at 100 mg L\(^{-1}\) concentration of MB shown in Fig. 4. The result (Fig. 4a) depicts that MB removal efficiency of DKGM slowly increased from 25.0% to 67.0% when DKGM dosage was increased from 2.0 to 20.0 g L\(^{-1}\). However, MB adsorption capacity of DKGM decreased from 12.5 to 3.4 mg g\(^{-1}\). It indicates that DKGM has poor adsorption for MB. A good adsorbent should have the strong binding ability to remove high concentrations of MB at low adsorbent doses. Compared with DKGM, SPI/DKGM composite beads have higher removal efficiency of MB. With an increase of adsorbent dosage, the maximum removal efficiency attained to 98.8% when SPI/DKGM composite beads dosage was increased to 0.8 g L\(^{-1}\). The maximum MB adsorption capacity of SPI/DKGM composite beads (201.2 mg g\(^{-1}\)) was achieved at
However, significant decrease in MB adsorption capacity was observed with further increase in SPI/DKGM composite beads dose. It is attributed to more available sorption sites for binding MB onto SPI/DKGM composite beads.

### 3.4. Effect of contact time and adsorption kinetics

UV–vis spectroscopy was applied to monitor the adsorption process of MB after adding SPI/DKGM composite beads. As shown in Fig. 5a, the intensity of the maximum adsorption peak at 665 nm dropped drastically within 7 min after SPI/DKGM composite beads were added. The maximum adsorption peak almost vanished after 9 min, indicating their rapid adsorption. Fig. 5b showed the effect of contact time on the removal of MB by SPI/DKGM composite beads at different MB concentrations (20 mg L⁻¹, 50 mg L⁻¹, 100 mg L⁻¹ and 200 mg L⁻¹). It was clear that the initial adsorption was rapid and all adsorption equilibriums were established within 12 min. The adsorption capacity (qₑ) for SPI/DKGM composite beads increased significantly from 15.9 mg g⁻¹ to 162.8 mg g⁻¹ at equilibrium when the MB initial concentration was increased from 20 to 200 mg L⁻¹. It is due to the strong electrostatic interaction between the cationic MB and the negatively charged SPI/DKGM composite beads.

To better understand the adsorption kinetics of MB by SPI/DKGM composite beads, the experimental data were fitted to various kinetic models, such as the pseudo-first order and pseudo-second order models. The integrated mathematical equations of first and second order kinetic models are expressed by Eqs. (3) and (4), respectively [45,46]:

\[
\log(qₑ - qₜ) = \log qₑ - \frac{k₁}{2.303} t
\]  (3)

\[
\frac{t}{qₜ} = \frac{1}{k₂qₑ²} + \frac{t}{qₑ}
\]  (4)

where \( qₑ \) (mg g⁻¹) and \( qₜ \) (mg g⁻¹) are the amounts of dye adsorbed per unit mass of adsorbate at time \( t \) and equilibrium, respectively; \( k₁ \) and \( k₂ \) are the first and second order kinetic rate constants, respectively. The plots of \( \ln(qₑ - qₜ) \) versus \( t \) and \( t/qₑ \) against \( t \) can be seen in Fig. 5c and d, respectively. Adsorption kinetics parameters are summarized in Table 1. The regression coefficients (\( R² \)) data in Table 1 indicated that the experimental kinetic data fitted better to a pseudo-second order model (\( R² > 0.994 \)) than to a pseudo-first order model (\( R² > 0.439 \)). The experimental values of \( qₑ \) were in close agreement with the calculated values of \( qₑ \) from the pseudo-second-order model, whereas the values of \( qₑ \) calculated from the pseudo-first-order model varied greatly. Since pseudo-second-order model is based on the assumption of chemical adsorption, this result implied that the adsorption process was due to chemisorption between MB and SPI/DKGM composite beads [47].

### 3.5. Adsorption isotherms and thermodynamics

Effects of initial MB concentration and temperature on the adsorption of MB by SPI/DKGM composite beads were shown in Fig. 6a. The adsorption capacity for MB firstly increased linearly with the increasing equilibrium MB concentration at 25, 35, 45, and 55 °C followed by a level off at equilibrium adsorption capacity. The equilibrium adsorption capacity decreased with increasing temperatures, which indicated that the adsorption process is exothermic in nature. The binding forces between MB molecule and SPI/DKGM composite beads may be broken at high temperature [25].
The linear Langmuir and Freundlich equations are expressed as Eq. (5) [48] and Eq. (6) [49], respectively:

\[
\frac{C_e}{q_e} = \frac{C_e}{q_{\text{max}}} + \frac{1}{q_{\text{max}}b}
\]

(5)

\[
\log q_e = \log K_f + \frac{1}{n} \log C_e
\]

(6)

where \(q_e\) (mg g\(^{-1}\)) and \(C_e\) (mg L\(^{-1}\)) are the amount of adsorbed MB per unit weight of adsorbent and MB concentration in solution at equilibrium, respectively; \(b\) (L mg\(^{-1}\)) is Langmuir constant relating the free energy of adsorption; \(q_{\text{max}}\) is the monolayer uptake capacity of the adsorbent; \(K_f\) and \(1/n\) are the Freundlich adsorption constant (mg g\(^{-1}\)) and adsorption intensity (dimensionless), respectively.

The Langmuir and Freundlich constants as well as the regression coefficients \((R^2)\) are calculated according to the corresponding slope and intercept of the linear plot of \(C_e/q_e\) versus \(C_e\) and \(\log q_e\) versus \(\log C_e\), respectively. The results are shown in Table 2. From Fig. 6b and c, it can be observed that the adsorption isotherms fitted Langmuir isotherm well in comparison with Freundlich isotherm. The regression coefficients \((R^2)\) data in Table 2 indicated that the Langmuir model \((R^2 > 0.998)\) fitted much better than the Freundlich model \((R^2 > 0.773)\). The maximum monolayer sorption capacities \((q_{\text{max}})\) were calculated to be 272.4 g g\(^{-1}\), 240.3 mg g\(^{-1}\), 202.4 mg g\(^{-1}\) and 178.5 mg g\(^{-1}\) at 25, 35, 45, and 55 °C, respectively. The calculated \(q_{\text{max}}\) values (Table 2) by the Langmuir model were close to the experimental values \(q_{\text{max}}\) (exp). The maximum monolayer sorption capacity decreased with increasing the temperature, exhibiting the exothermic nature of the adsorption process.

To investigate the adsorption processes, the changes of thermodynamic parameters, such as standard enthalpy \((\Delta H^\circ)\), standard entropy \((\Delta S^\circ)\), and standard free energy \((\Delta G^\circ)\), must be determined using Van’t Hoff equation [50]:

\[
\ln K_c = \ln \frac{q_e}{C_e} = \frac{\Delta S^\circ}{R} - \frac{\Delta H^\circ}{RT}
\]

(7)

\[
\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ
\]

(8)

where \(K_c\) is the equilibrium constant, \(R\) is the gas constant (8.314 J K\(^{-1}\) mol\(^{-1}\)), \(T\) is the temperature in Kelvin, \(q_e\) is the amount of adsorbed MB per unit weight of adsorbent at equilibrium (mg g\(^{-1}\)), and \(C_e\) is the equilibrium concentration of MB in the solution (mg L\(^{-1}\)).
The $\Delta H^\circ$ and $\Delta S^\circ$ can be calculated from the slope and intercept of Eq. (7), plot of ln $K_c$ versus $1/T$ (shown in Fig. 6d). Thermodynamic adsorption parameters for the MB adsorption on SPI/DKGM composite beads were listed in Table 3. The negative value of $\Delta H^\circ$ indicates that the adsorption is an exothermic process. The negative value of $\Delta S^\circ$ shows a decreased disorder at the solid–liquid interface during MB adsorption. As the temperature increases, the mobility of MB molecules increasing caused the MB molecules to escape from the solid phase to the liquid phase. The negative values of $\Delta G^\circ$ decreased with an increase of temperature. It suggests that the adsorption is a spontaneous process and the adsorption process is favorable at lower temperature. Similar results were found by other researchers [23,51].

### Table 2

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<td>$q_{\text{max}}$ (mg g$^{-1}$)</td>
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### Table 3

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### 3.6. Regeneration studies

Regeneration of adsorbents for repeated reuse is an important parameter in industrial application. It was found that the adsorption behavior of MB onto SPI/DKGM composite beads was much dependent on pH value. At low pH value, desorption would be triggered with the electrostatic interaction disappearing between MB and SPI/DKGM composite beads in acid solution. Comparing the adsorption data and desorption data, the desorption ratio was calculated as 97% in 0.01 M HCl solution. The adsorption–desorption cycle of SPI/DKGM composite beads was shown in Fig. 7. The
adsorption capacity decreased slightly but steadily over the four cycles. SPI/DKGM composite beads can be repeatedly used for the adsorption of cationic dyes.

4. Conclusion

SPI/DKGM composite beads were prepared to remove methylene blue from aqueous solution. SEM observations showed the porous structure of SPI/DKGM composite beads. SPI/DKGM composite beads showed fast adsorption of MB from aqueous solutions at pH 6.0. The remarkable adsorption performance can be attributed to SPI immobilized on DKGM. The kinetic study showed that the adsorption process followed a pseudo-second-order model. The Langmuir model represented the best fit isotherm model, giving a maximum adsorption capacity of 272.4 mg g⁻¹ at 298 K. SPI/DKGM composite beads could be a good candidate for the purification of water contaminated by organic dyes.

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