

A Novel Adsorbent Obtained by Caging Activated Carbon by Konjac Glucomannan Gel for Elimination of Organic Compounds

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ABSTRACT: In this study, the adsorptive ability of the konjac glucomannan gel containing activated carbon (KGMG-AC) was investigated by measuring the removal of several organic compounds with different charges, such as nitrobenzene (NB), methylene blue (MB), and rose bengale (RB). The physical and chemical properties, adsorption dynamics, adsorption isotherms, and the effect of pH of the adsorbents were compared with those of a commercially available powdered activated carbon (AC). The results of the present study indicate that the removal ratio of NB, MB, and RB onto KGMG-AC was slightly higher than that of the AC. The adsorption equilibrium constant (K_L) value (0.02 L/mg) of KGMG-AC for NB was similar to that of AC (0.03 L/mg). However, the saturated adsorption amount (Q_0) of KGMG-AC (368 mg/g) for NB was slightly larger than that of AC (354 mg/g). The saturated adsorption amounts of MB and RB on KGMG-AC were 302 and 259 mg/g, respectively. On the other hand, a high molecular weight humic acid was not adsorbed by KGMG-AC. Thus, entrapping AC into KGMG resulted in the selective adsorption. Therefore, this study could show that KGMG-AC was a new environmental friendly adsorbent that can be easily prepared, used, and recovered in environments.

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KEYWORDS: adsorption; colloids; kinetics

Received 25 October 2013; accepted 30 January 2014

DOI: 10.1002/app.40542

INTRODUCTION

Environmental pollution caused by organic compounds in industrial effluents is one of the most pressing problems in the world. Strict legislation on the discharge of these toxic products makes it necessary to develop various efficient technologies for the removal of organic substances from tap water and wastewater.¹ Many kinds of technology and processes are currently used for removing organic compounds from industrial effluents. Those are biological treatments,² membrane processes,³ advanced oxidation processes,^{4,5} chemical, and electrochemical methods,⁶ and physical adsorption.⁷⁻⁹ The process involving

activated carbon (AC) for adsorption is regarded as one of the most efficient processes, because AC is the widely employed as a conventional adsorbent due to its high adsorption capacity for a variety of organic substances.¹⁰ Although AC is not so expensive, but its cost is not low enough to permit the consumption of adsorption sites by a large quantity of substances other than the intended compound to be removed. Furthermore, the management of treatment plants for pollutants in which AC is used is not easy because of the dispersion of AC powder.

On the other hand, konjac plant is grown in China, Korea, Japan, and southeast Asia for its large starchy corms, used to

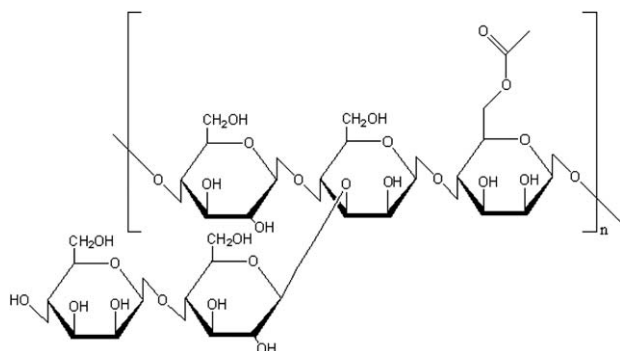


Figure 1. Chemical structure of konjac glucomannan (KGM).

create a flour and jelly. The output of konjac plant was about 375,000 tons in the whole world in 2005.¹¹ Glucomannan comprises 40% by dry weight of the roots, or corm, of the konjac plant. Glucomannan is also a hemicellulose that is present in large amounts in the wood of conifers and in smaller amounts in the wood of dicotyledons. Glucomannan is also a constituent of bacterial, plant, and yeast membrane with differences in the branches or glycosidic linkages in the linear structure. Konjac glucomannan (KGM) is a food additive used as an emulsifier and thickener based on it is abundant, safe, and cheap. So if KGM gel is made possible using embedded material in the environmental field, KGM gel embedded with AC would become a novel type enclosed adsorbent. KGM is a high-molecular weight water-soluble nonionic natural polysaccharide isolated from the tubers of the *amorphophallus konjac* plants. It has a linear random copolymer of β-1,4 linked D-mannose and D-glucose in a molar ratio of 1.6 : 1 with about 1 in 19 units being acetylated.^{12–14} The gelation structure of KGM (see Figure 1) was provided by Alonso-Sande et al.¹⁵ The molecular weight of KGM is $\sim 10^6$ and it has many advantages such as, nontoxic, low cost, having excellent film-forming ability, good biocompatibility, biodegradability, and a high viscosity.¹⁶ Because of these physical and chemical characteristics, KGM has been widely used in packing and preservatives material,^{17–19} controlling released material,²⁰ wood adhesives,²¹ enzyme entrapment,²² and drug carrier.²³ KGM gel (KGMG) is formed by heating a KGM solution in the presence of alkali compound or higher amount of neutral salt.^{24,25} The hydrogen bonds and hydrophobic interactions between the KGM chains after removing acetyl groups (5–10%) forms a network gel structure of KGMG.^{15,26–28} KGMG has long been used as a noncalorie health-care food classified as indigestible dietary fiber in China and Japan in the food industry. In the environmental field, crosslinked carboxymethyl KGMG has been used as a new material for the removal of heavy metal ions such as Cd^{2+} , Cu^{2+} , and Pb^{2+} , with different degrees of substitution.²⁹ However, the investigation of KGMG containing AC used for adsorbing organic compounds has not been reported so far. The investigations of alginate gel (AG) beads containing carbon nanotubes and AC had been reported.^{30,31} Although the adsorption capacity of the adsorbent based on AG for organic compounds is adequate, AG is relatively expensive. Therefore, inexpensive, abundant and safe cage

entrapping adsorbents for contaminants is urgently needed. In this study, the KGMG–AC was prepared by reaction with calcium hydroxide and, the adsorptive properties of these KGMG–AC was investigated using the different charges of different compounds, such as using NB, MB, and RB as adsorbates. Moreover, the physical and chemical properties, adsorption dynamics, adsorption isotherms, and the effect of pH of the adsorbents (KGMG–AC and KGMG) were compared with those of commercially available AC. The results of the present study indicated that the adsorption capacity for NB, MB, and RB of the KGMG–AC was nearly equal to those of the commercially available AC.

MATERIALS AND METHODS

Materials

The KGM powder was purchased from Ogino Company Ltd. (Gunma, Japan) and further purified by mixing KGM powder with three times the weight of 50 and 80 wt % ethanol for 2 h and with waterless ethanol for 4 h and then was dried at 60°C for 4 h according to the reported method.²⁴ AC powder, MB, NB, RB, sodium alginate (300–400 cP), calcium chloride, glutaraldehyde, and ethanol were purchased from Wako Pure Chemicals. (Osaka, Japan). Calcium hydroxide (Wako Pure Chemical Industries, Osaka, Japan) of reagent grade was used as an alkaline coagulant. The properties of AC for particle size, average pore size, and surface density were 33.6 μm, 4.27 nm, and 0.45 g/cm³, respectively. The AC was dried for 24 h in an oven maintaining the constant temperature at 110°C. Humic acid was prepared by extraction from peat soil at Bibai in Hokkaido followed by purification according to the protocol recommended by the IHHS (International Humic Substances Society). The water used in this study was doubly distilled water.

Preparation of KGMG. The powder of 10.5 g (3%) KGM was dispersed in 300 mL distilled water in a round-bottomed flask equipped with a mechanical stirrer (K-1RN, as One, Osaka, Japan) at 400 rpm for 1 h at room temperature. The dispersion was heated in a water bath to 60°C and held at 60°C for 30 min. Then 40 mL of 0.14M aqueous solution of calcium hydroxide was added, and the hot mixture was stirred continuously at 200 rpm for 10 min and cooled to room temperature in bowl to form KGMG. After cutting (the size of the KGMG was about $3 \times 3 \times 2$ mm³), these pieces of KGMGs were filtered and washed with double distilled water overnight and then used in the adsorption experiments.

Preparation of KGMG–AC. After mixing 3.5 g (1%) of AC with 300 mL of 3–6% KGM solution, the solution was dispersed for 1 h and the same procedure of shown in section “Preparation of KGMG” as used in the preparation of KGMG was carried out.

Preparation of Alginate Gel Beads Entrapped with Activated Carbon (AG–AC). After mixing 3.5 g (1%) of AC with 300 mL of 3% alginate solution, the solution was added from a burette to a 0.9M (10%) calcium solution to form the beads of AG–AC. The diameter of the AG–AC beads was about 3 mm. These beads were filtered and washed with double distilled water

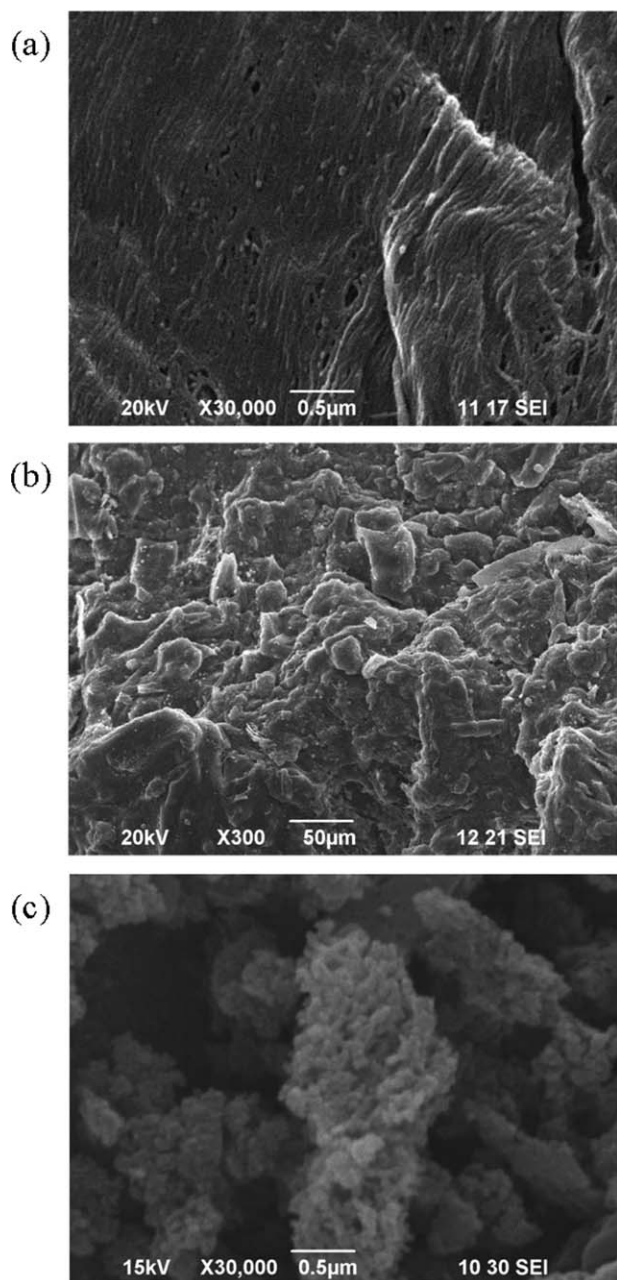


Figure 2. SEM images of the (a, $\times 30,000$) KGMG-AC, (b, $\times 300$) KGMG-AC, and (c) AC.

overnight and then used in the adsorption experiments to compare the ability with that of KGMG-AC.

Physical and Chemical Characteristics of KGMG-AC, AC, and KGMG

The surfaces of KGMG-AC and AC were observed by using a scanning electron microscope (SEM), JSM-6360LA (Jeol, Tokyo, Japan) after KGMG-AC was fixed in glutaraldehyde (2% v/v) overnight at room temperature and dehydrated with a graded ethanol series (50–100% v/v) by using the method of Ederli et al.³² The BET surface area for KGMG-AC, AC, and KGMG were measured using a surface analyzer AUTOSORB 6AG (Yuasa Ionics, Osaka, Japan). A 0.1 g sample from one of these

mixtures KGMG-AC, AC, or KGMG was put into a glass sampler after fixation by glutaraldehyde, dehydration with ethanol, and freeze-dried. Then, the BET surface area was evaluated using the BET method based on N_2 adsorption isotherms.³³ Elemental analyses were performed on a sample of KGM at the Instrumental Analysis Center of Hokkaido University using a *CHN CORDER MT-6* (Yanagimoto, Japan).

The point of zero charge (pH_{PZC}) was determined for KGMG-AC, AC, and KGMG using the acid–base titration method of Faria et al.³⁴ A 0.01M NaCl solution was aliquoted (50 mL) into a series of flasks. The initial pH ($pH_{initial}$) was adjusted from 2 to 13 by addition of 0.1M HCl or NaOH. A 0.1 g sample of either KGMG-AC, AC, or KGMG was added to each flask, followed by agitation (165 rpm) for 4 days at 25°C. Then, the final pH (pH_{final}) of the mixtures was measured. The pH_{PZC} was defined as the point at which the curve determined by $pH_{final} - pH_{initial}$ crossed the line of $pH_{initial} = pH_{final}$. The pH was measured using a portable pH meter (HORIBA M12 and M13).

A constriction test of KGMG-AC (the content were 3–6% for KGM and 1% for AC) was carried out using the electronic universal tester RTC-1310A (Orientec, Japan) at the constriction speed of 1 mm/min. The samples were cut and polished into a $2.0 \times 2.0 \text{ mm}^2$ cross-section and a gauge length of 10.0 mm. For each date point, five samples were tested and average value was taken.

Adsorption Experiments

The pH of an aqueous solution of 25 mL of 50 mg/L NB, MB, and RB was adjusted to pH 7 using 0.01M phosphate buffer solution. The solution was then poured into a 100 mL flask with a stopper. KGMG-AC (KGMG: 1 g containing AC: 10 mg) or AC (10 mg), KGMG (1 g) was then added to the solution and the mixture was shaken at 165 rpm in a temperature-controlled shaker, for 0–300 min at 25°C. After the samples were centrifuged at $30,000 \times g$ for 30 min, 5 mL of the supernatant was withdrawn from the flasks to determine the concentration of NB, MB, and RB by an ultraviolet visible spectrophotometer V-550 (Jasco, Tokyo, Japan) at 268 nm, 665 nm, and 548 nm, respectively. The experiment was repeated three times for each condition and the average of the three trials was calculated. The relative standard deviation from three measurements was $\sim 5\%$.

To obtain the adsorption equilibrium curves, 25 mL of aqueous solutions (pH 7) of either NB, MB, or RB in initial concentration ranging from 0 to 200 mg/L were poured into a 100 mL flask with a stopper. The samples of KGMG-AC (KGMG: 1 g containing AC: 10 mg) or AC (10 mg) were added to the flask and the mixture was shaken for 24 h (at 25°C and 165 rpm). Subsequently, the mixture was centrifuged and the concentration of NB, MB, and RB was analyzed.

RESULTS AND DISCUSSIONS

Physical and Chemical Characteristics

To compare the surface charge density of the KGMG-AC, AC, and KGMG, we measured pH_{PZC} as well as the specific surface area. The pH_{PZC} values of KGMG-AC, AC, and KGMG were 7.4, 7.2, and 7.4, respectively. These results indicated that the

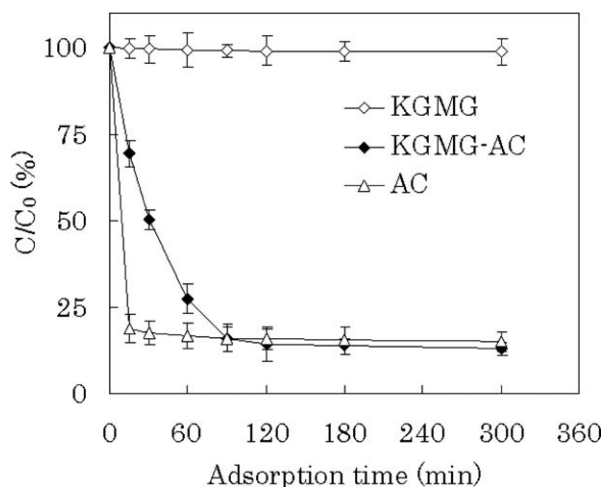


Figure 3. Removal ratio as a function of adsorption time on nitrobenzene (NB) using AC (10 mg), KGMG-AC (KGMG: 1 g containing AC: 10 mg), KGMG (1 g), 25 mL of 50 mg/L NB, pH 7, at 25°C, C , the adsorption equilibrium concentration (mg/L) and C_0 , the initial concentration (mg/L).

surface charges of KGMG-AC, AC, and KGMG were almost zero as long as there was neutral pH. The surface density of the KGMG-AC, AC, and KGMG were 1.24, 0.45, and 1.23 g/cm³, respectively. The BET surface area of KGMG-AC and KGMG were 221 and 77 m²/g, respectively. The BET surface area of KGMG-AC was much lesser than that of AC (1432 m²/g), because the polymer structure of KGMG do not have so many pores like AC. Figure 2 (a 30,000×) shows SEM micrographs of KGMG-AC is a structure of network by the KGM molecular chains from the hydrogen bonds and hydrophobic interactions between the KGM chains after removing acetyl groups.¹⁵ There is very rough on the surface of KGMG-AC; however, it is very difficult to find AC particles dispersed in the KGMG matrix in Figure 2 (b, ×300). Obviously, Figure 2 (c) can be found that there is very rough on the AC surface. An elemental analysis of KGM was carried out in this study. The following composition of KGM: 39.78% C, 6.05% H, 49.27% O, and 4.90% ash, respectively. There was most of the elements of C and O in the KGM molecular. The ratios of the elements of C and O in the KGM were much more than that of H and Ash.

Effect of Contact Time on NB, MB, and RB Adsorption

The mixtures of 25 mL of 50 mg/L NB, MB, or RB, and 1 g of KGMG-AC (containing AC: 10 mg), or 10 mg of AC, or 1 g of KGMG in an aqueous solution, were shaken for either 0, 15, 30, 60, 90, 120, 180, 300 min at 25°C and 165 rpm in order to examine the relationship between the amount of NB, MB, RB adsorbed and contact time. As indicated in Figure 3, both KGMG-AC and AC in adsorption equilibrium was reached within ~120 min. The removal ratios of NB from an aqueous solution (NB: 50 mg/L) on KGMG-AC and AC after 5 h were 87% and 85%, respectively, while the removal ratio of only KGMG was 1.2%, under the same experimental conditions. The effect of contact time on MB and RB was investigated. In this case, the maximal adsorption for AC occurred very rapidly (~15 min), but it took ~120 min for KGMG-AC to reached adsorption equilibrium. The removal ratio of KGMG-AC, AC,

and KGMG after 5 h were 84%, 81%, 8.3%, for MB (MB: 50 mg/L) and 78%, 76%, 12.8% for RB (RB: 50 mg/L), respectively.

A neutral compound NB was adsorbed strongly and rapidly by AC. Positively charged MB and negatively charged RB were also adsorbed by AC although the removal ratios of MB and RB were slightly lower than that of NB. Thus AC can adsorb many types of substances regardless of charge. However, NB, MB, and RB were scarcely adsorbed to the KGMG because KGM gel has no charge (neutrality) and it was scarcely influenced by the charge in the process of adsorption. On the other hand, when AG was used as a negatively compound, it resembled how MB was adsorbed strongly because of the electrostatic interactions with the negatively charge of AG. The removal ratio of NB, MB, and RB onto KGMG-AC was slightly higher than that of the

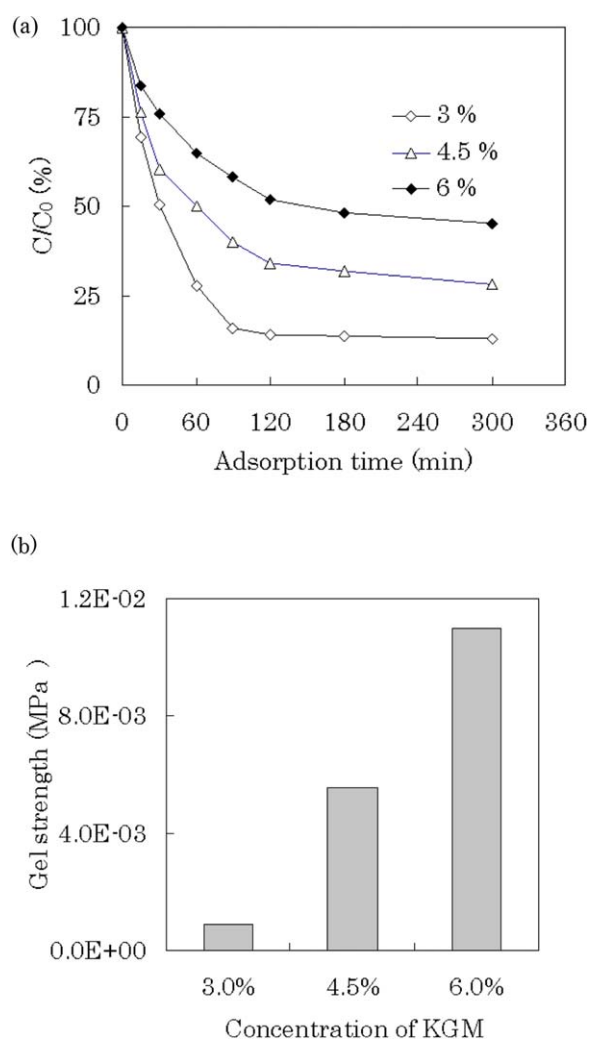


Figure 4. (a) Effect of adsorption rate on nitrobenzene (NB) using KGMG-AC (the content were 3–6% for KGM and 1% for AC) (KGMG: 1 g containing AC: 10 mg), 25 mL of 50 mg/L NB, pH 7, at 25°C. (b) Effect of concentration of KGM on gel constriction strength KGMG-AC (the content were 3–6% for KGM and 1% for AC) (at the constriction speed of 1 mm/min, at 25°C). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

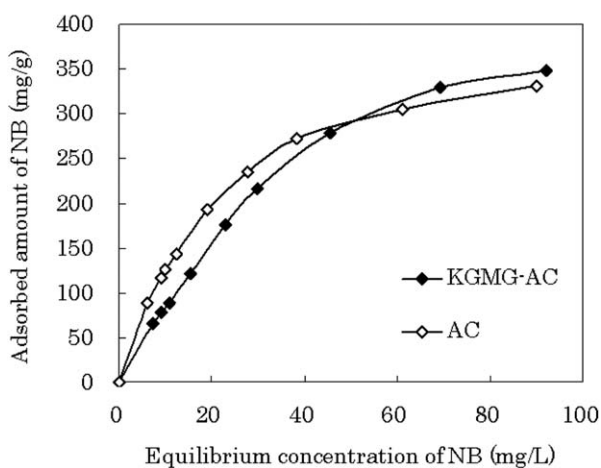
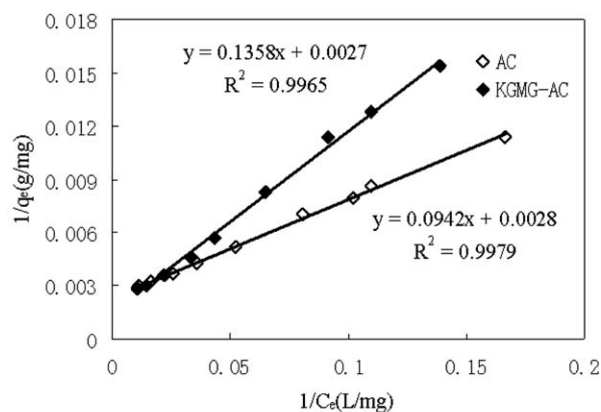


Figure 5. Adsorption isothermal curve of nitrobenzene (NB) on KGMG-AC and AC, AC (10 mg), KGMG-AC (KGMG: 1 g containing AC: 10 mg), 25 mL of 0–200 mg/L NB, pH 7, at 25°C, adsorption time of 24 h.

AC. It was confirmed that KGMG was able to be used as the carrier of power AC.

To clarify the effect of KGMG on adsorption of NB into AC enclosed in KGMG, an adsorption experiment was carried out using 50 mg/L NB and KGMG-AC (the content were 3–6% for KGM and 1% for AC). Figure 4 (a) shows that the speed of adsorption was decreased with the increase of content (3–6%) of KGM in KGMG-AC and the result confirmed that the blocking effect from the gel structure of KGMG-AC was increased with the increase of KGM content in gel when contaminant was adsorbed on AC through the wall of gel. Moreover, the result in Figure 4(b) of constriction test using KGMG-AC (the content were 3–6% for KGM and 1% for AC) shows the constriction strength of the gel was increased with the increase of KGM content (3–6%) in KGMG-AC. The constriction strength (1.1×10^{-2} MPa) of the gel (the content were 6% for KGM and 1% for AC) has doubled that (0.56×10^{-2} MPa) of the gel (the content were 4.5% for KGM and 1% for AC) and was ~ 10 -fold greater than that (0.09×10^{-2} MPa) of the gel (the content were 3% for KGM and 1% for AC). The increase in gel constriction strength means that the amount of KGM in KGMG-AC was increased; however, the coat for complex of KGMG-AC was

Table I. Parameters of the Langmuir Model for Nitrobenzene Adsorption Isotherms

Sample	Q_0 (mg/g AC)	K_L (L/mg)	R^2
KGMG-AC	368	0.02	0.99
AC	354	0.03	0.99

increased. It is not suitable for get into shape if KGMG-AC with KGMG less than 3% was used by the preliminary experiment of preparation of KGMG-AC. Therefore, KGMG-AC (3% for KGM and 1% for AC) was proper for the use in real environments for treatment of contamination.

Adsorption Isotherms for NB, MB, and RB

The kinetic data in Figure 3 shows that the equilibrium of adsorption was achieved in less than 30 min for AC and 2 h for KGMG-AC. However, for the adsorption isotherm experiment, a period of 24 h was selected to allow enough time for equilibrium. The adsorption isotherms for KGMG-AC and AC were measured at 25°C and pH 7. As indicated in Figure 5, the isothermal curves of NB for KGMG-AC and AC showed a typical Langmuir-type pattern. The relationship between the reciprocal of the amount of NB adsorbed on KGMG-AC and AC and the

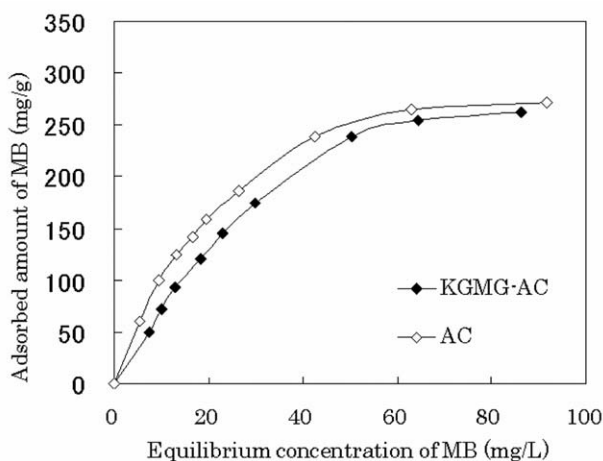
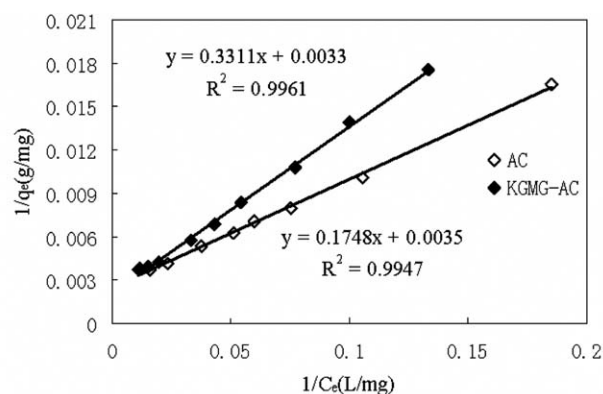


Figure 6. Adsorption isothermal curve of methylene blue (MB) on KGMG-AC and AC, AC (10 mg), KGMG-AC (KGMG: 1 g containing AC: 10 mg), 25 mL of 0–200 mg/L MB, pH 7, at 25°C, adsorption time of 24 h.

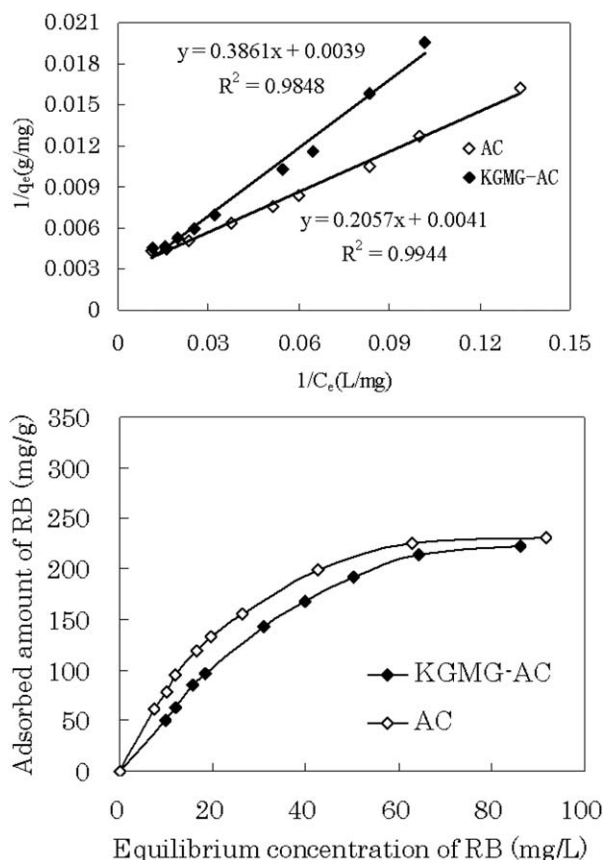


Figure 7. Adsorption isothermal curve of rose bengale (RB) on KGMG-AC and AC, AC (10 mg), KGMG-AC (KGMG: 1 g containing AC: 10 mg), 25 mL of 0–200 mg/L RB, pH 7, at 25°C, adsorption time of 24 h.

reciprocal of the equilibrium concentration of NB in the solution was linear. The parameters in eq. (1), which were determined from adsorption isotherms for KGMG-AC and AC, are summarized in Table I.

$$q_e = \frac{Q_0 K_L C_e}{1 + K_L C_e}, \quad (1)$$

Here, q_e is the amount adsorbed (mg/g); Q_0 , the saturated adsorption amount (mg/g); K_L , the adsorption equilibrium constant (L/mg); and C_e , the adsorption equilibrium concentration (mg/L).

The shape of the adsorption isotherm of KGMG-AC was very similar to that of AC, Table I shows the K_L value (0.02 L/mg) of KGMG-AC was similar to that of AC (0.03 L/mg). On the other hand, the Q_0 value of KGMG-AC (368 mg/g) was slightly larger than that of AC (354 mg/g). This small difference is due to the

distribution of NB in water in the gel beads. Therefore, in order to precisely estimate the value of Q_0 for KGMG-AC, it is necessary to subtract the amount distributed into the water in the gel from the value in Figure 5. The Q_0 obtained from the adsorption isotherm, where the corrected values were plotted, was 354 mg/g, this value was the same as that for AC (354 mg/g). These results confirmed that the adsorption constant of KGMG-AC was reduced by being surrounded by KGMG, but the adsorption capacity of KGMG-AC did not change from the original AC.

If sufficient time to achieve the equilibrium was involved, KGMG-AC would have a similar ability to that of AC. As indicated in Figures 6 and 7, the adsorption isotherms of MB and RB for KGMG-AC and AC were measured under the same conditions. As shown in Table II, the results obtained for MB and RB for KGMG-AC and AC were very similar to those of NB. The results obtained from the study of adsorption ability for NB, MB, and RB by KGMG-AC were very similar to those of organic compound employing AG-AC.³¹ That is, in order to separate the pollutants, KGMG or AG beads is able to be used as good carrier for AC power, and the adsorption capacity of AC in KGMG does not change from the original AC.

The pH_{PZC} values of KGMG and AG were 7.4 and 2.7, respectively. These values indicated that KGMG was almost zero charged as long as pH was neutral; however, AG is negatively charged over a wide pH range i.e., from acid to basic regions. Thus, KGMG-AC with the neutral charge was scarcely influenced by ion of metal against the AG-AC with negative charge on the surface in the process of adsorption.

Evaluation of Adsorption Capacity for KGMG-AC and AG-AC on NB

To compare the adsorption capacity for KGMG-AC and AG-AC the functional removal ratio was investigated using mixtures of 50 mg/L NB and KGMG-AC (KGMG: 1 g containing AC: 10 mg) and AG-AC (AG: 1 g containing AC: 10 mg) at 25°C and pH 7. Figure 8 shows the removal ratio of KGMG-AC for 50 mg/L NB solution was larger than that of AG-AC. It was thought that the block from the gel structure of KGMG-AC was less than that of the AG-AC. Therefore, the KGMG was excellent as the gel material for containment of AC in it.

On the other hand, negatively charged RB was not adsorbed to AG because of the electrostatic repulsion between negative charges on RB and AG. However, KGMG was able to adsorb RB because KGMG has neutral charge. Therefore, there is a large advantage and possibility in practical application of KGMG-AC to negatively charged compounds.

Table II. Parameters of the Langmuir Model for Methylene Blue and Rose Bengal Adsorption Isotherms

Samples	methylene blue			rose bengale		
	Q_0 (mg/g AC)	K_L (L/mg)	R^2	Q_0 (mg/g AC)	K_L (L/mg)	R^2
KGMG-AC	302	0.01	0.99	259	0.01	0.98
AC	286	0.02	0.99	243	0.02	0.99

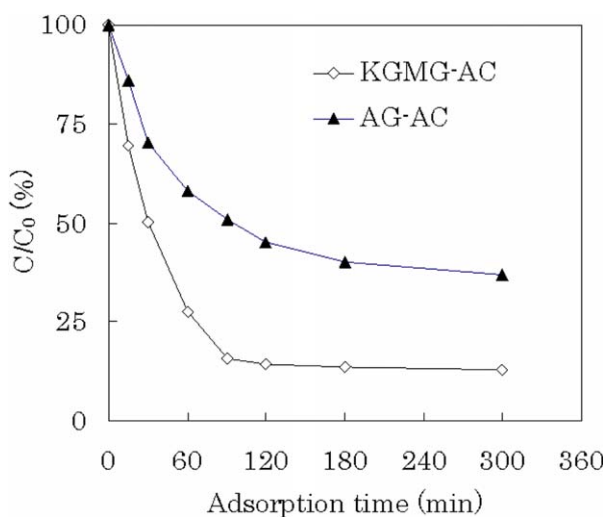


Figure 8. Effect of adsorption rate on nitrobenzene (NB) adsorption by KGMG-AC (KGMG: 1 g containing AC: 10 mg) and AG-AC (AG: 1 g containing AC: 10 mg) (25 mL of 50 mg/L NB, pH 7, at 25°C). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

The Effect of pH for KGMG-AC

The pH of solution is one of the most important parameters affecting the adsorption process. To determine the effect of pH on adsorption capacity of KGMG-AC, NB, and MB solutions were prepared at different pH values ranging from 2 to 12. The dependence of pH on the adsorption of NB and MB at an initial concentration of 50 mg/L onto KGMG-AC. Obviously, the adsorption capacities of KGMG-AC for NB were not affected by pH over the range examined in this study (pH 2–12). While, the adsorption ability of KGMG-AC for MB somewhat depended on the pH of the solution, in particular, the adsorption ability increased in higher pH than pH_{PZC} (Figure 9).

Adsorption Capacity for AC and KGMG-AC on Humic Acid

Humic acid is a principal component of humic substances, which are the major organic constituents of soil, is widely distributed in

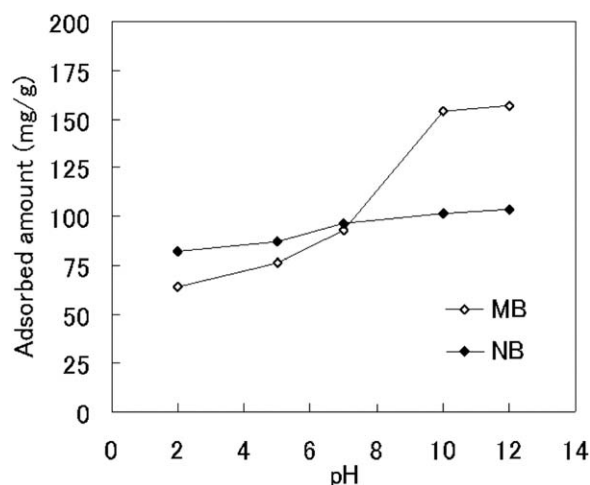


Figure 9. Effect of solution pH on the adsorption of nitrobenzene (NB) and methylene blue (MB) onto KGMG-AC of 1 g, 25 mL of 50 mg/L NB and MB, pH 7, ionic strength = 0.01M, at 25°C, and adsorption time of 24 h.

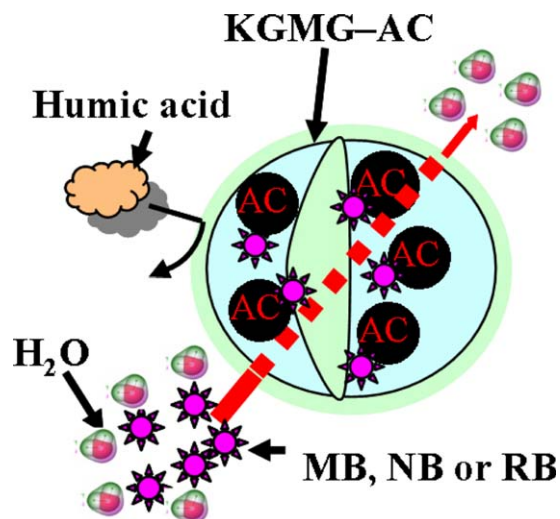


Figure 10. Schematic representation of the advantageous performances on the adsorption of organic compounds [such as nitrobenzene (NB), methylene blue (MB), and rose bengale (RB)] to konjac glucomannan gel containing activated carbon (KGMG-AC). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

the aquasphere and plays important roles in supplying nutrients to plants and microbial organisms and in maintaining the structure of soil. Since humic substances are very important components in agricultural water, it is usually not necessary to remove it, except when it is used for tap water. Therefore, new materials which can selectively adsorb low molecular weight compounds but do not adsorb high molecular weight polymers, such as humic substances, are needed. The mixtures of 25 mL humic acid, and 1 g of KGMG-AC (containing AC: 10 mg), or 10 mg of AC in an aqueous solution were shaken for 5 h at 25°C. As a result, the percent of humic acid for AC adsorbed from an aqueous solution (humic acid: 100 mg/L) after 5 h was 47%; however, it is noteworthy that humic acid was not adsorbed at all to KGMG-AC.

The gel structure of KGM around the AC might suppress the transport of humic acid to the AC entrapped within the KGMG and the KGM gel could become a barrier to the approach of low molecular weight compounds, such as NB, MB, RB to the AC in the KGMG. It was confirmed that when AC is entrapped into an KGM gel, the selective adsorption of several organic compounds to AC results (Figure 10). It shows that KGMG-AC has the potential for the selective removal of agricultural chemicals without changing the fundamental water quality, that is, by maintaining useful components such as humic acids in agricultural water.

CONCLUSION

We examined the adsorption properties of the KGMG-AC for the development of a new adsorbent that can be easily separated from pollutants. This material has a high ability for adsorption of NB, MB, and RB. The saturated adsorption amounts of NB, MB, and RB on KGMG-AC were 368, 302, and 259 mg/g, respectively. These values were slightly larger than that of AC itself. On the other hand, the price of KGMG is relatively inexpensive than that of AG, and KGMG-AC has a large advantage to adsorb negatively charged compounds more than that with AG-AC having negative charges.

The results in this study suggest that KGMG–AC has the potential for removing agricultural chemicals at low concentrations from large amount of dissolved organic matter such as humic substances in water and that KGMG–AC can lead to the success in the treatment of and the long life of AC, thus lowering the overall cost. As a result, this study has shown that the konjac glucomannan gel containing AC is mechanically strong, easy to produce, easy to separate, and it is totally an environmental friendly adsorbent. Since this material has high adsorption ability, this adsorbent could be applied for adsorption of large quantities of NB, MB, and RB if they were accidentally spilled into the environment.

ACKNOWLEDGMENTS

The very helpful comments provided by the reviewers of this manuscript are gratefully acknowledged. This work was supported by Open Project of State Key Laboratory of Urban Water Resource and Environment Harbin Institute of Technology (HC201322) and Open Project of Key Laboratory of National Education Department, Northeast Agricultural University (SB11B01). This work was also supported by the Scientific Research Foundation for the Doctor of Northeast Agricultural University (2012RBC31) and National Science and Technology Research Program of China (2012BAD06B02-01-04-02). This study was also supported by Natural Science Foundation of Heilongjiang Province of China (C201301) and Educational Commission of Heilongjiang Province of China (10531012). The authors are grateful to Dr. Jianping Gong and Dr. Taolin Sun of the Graduate School of Science of Hokkaido University, for their assistance with the measurements of the gel strength. The authors are also grateful to Dr. Katsuyoshi Nishinari of the Graduate School of Human Life Science of Osaka City University and Dr. Hongbin Zhang of the School of chemistry and chemical engineering of Shanghai Jiaotong University for their experimental support in the study.

AUTHOR CONTRIBUTIONS

Dr Yingjie Dai performed the experiments of scanning electron microscope (SEM) and the constriction test of KGMG–AC. Dr Yingjie Dai and Dr Shunitz Tanaka supervised the research and wrote the manuscript. Dr Hong Yan, Dr Binbin Zhang, Wenting Wu, and Liqiong Yang performed the experiments of the properties of AC for particle size, average pore size and surface density. Dr Shufeng Li, Dr Wenbin Li, and Dr Hongtao Li performed the experiments of the effect of pH of the adsorbents (KGMG–AC and AC) and that of preparation of KGMG–AC and KGMG. Dr Lilong Yan, Dr Dexin Shan, and Dr Yujie Feng performed the experiments of adsorption isotherms and adsorption dynamics for KGMG–AC, AC, KGMG and AG-AC. Dr Norifumi Terui performed the experiments of the point of zero charge (pHPZC) of KGMG–AC, AC and KGMG.

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