Chemically modified styrene butadiene styrene, characterization and adsorbent application for metal ions removal from aqueous solution

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ABSTRACT

In this study, the styrene-butadiene-styrene was modified with various processes like nitration, reduction and then cross-linked with cross-linking agents glutaraldehyde. The Fourier transform infrared spectrometer (FT-IR) study showed that the styrene-butadiene-styrene was chemically modified by various processes like nitration, reduction and then cross-linked by crossing linking agent glutaraldehyde. The morphological study showed that the surface of chemically modified styrene-butadiene-styrene (CM-SBS) is more heterogeneous and porous as compared to pure styrene-butadiene-styrene (SBS). The adsorbents were also characterized by energy dispersive X-rays (EDX) and pH_{pzc}. The CM-SBS and styrene butadiene styrene (SBS) was used as an adsorbent for the removal of Cu(II) and Pb(II) ions from aqueous solution. It was found that the CM-SBS adsorbed 0.18 and 0.06 mmol g^{-1} while pure SBS adsorbed 0.1 and 0.03 mmol g^{-1} of Cu(II) and Pb(II) ions, respectively. The kinetic study showed that the adsorption study followed pseudo-second-order kinetics, which indicated that the chemical sorption is the rate-limiting step. The obtained adsorption data were also fitted to Langmuir, Freundlich and Temkin isotherms, which followed the entire models. It was also found that the Freundlich model presents the best result than Langmuir and Temkin isotherms.

Keywords: Styrene butadiene styrene; Adsorption; Morphology; Adsorption isotherms; Adsorption kinetics

1. Introduction

From the last decade, environmental pollution and its harmful effects on the environment have been studied. The concentration of pollutants increases as it increases industrialization [1]. Various metals are extremely toxic for humans, animals and plants. The majority of the metals enter the ecosystem through the consumption of contaminated drinking water, marine, animal foods, plants grown-up in metal-contaminated soil, inhalation of dust and direct ingestion in soil [2,3]. Intake of toxic metals takes place in humans through the food chain. The toxic metals concentration in human bodies is directly proportional to the consumption of foods that are rich in toxic metals. Lead (Pb) is used in a number of industrial activities like ceramic and glass industries, acid battery manufacturing

metal plating/finishing, ammunition. The World Health Organization (WHO) permissible limits of Pb is about 0.05 mg L^{-1} whereas the maximum contaminant level (MCL) of Pb ions in drinking water is set as 0.015 mg L^{-1} [4,5]. The toxicity of Pb includes damaging kidneys, disruption of the biosynthesis of hemoglobin and anemia, disruption of the nervous system, rise blood pressure, reduce learning abilities in children, and brain damage.

Copper(Cu) arises from various industrial activities such as motor vehicles, fertilizers, conductor, basic steelwork foundries, pulp and paper mills, petroleum refineries and non-ferrous metal works. The United State Environmental Protection Agency (US EPA) show Cu concentration limit is 1.3 mg L^{-1} while the world health organization (WHO) limit of Cu ions is1.5 mg L^{-1} in drinking water [6,7]. The acute and chronic effects of Cu are headaches, dizziness, vomiting and diarrhea, gastrointestinal catarrh, nose irritation, mouth and eyes cramps in the calves, stomach-aches and skin

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dermatitis. High uptakes of Cu may cause kidney and liver damage and even death.

The most widely used methods for removing toxic metals are electrochemical precipitation, chemical and ion-exchange membranes, and adsorption. Among these techniques adsorption is one of the most common and effective processes used for the removal of metal ions. Because in chemical and electrochemical precipitation methods the disposal of precipitated wastes has a great problem while the ion-exchange membranes method is an expensive technique [8–11]. Extensive research is going on adsorption technique, where the researchers reported that the microorganisms [12], clay [13], wood materials [14,15], humic acid [16], aquatic plants [17], agricultural byproducts [18], natural zeolite [19], and other low-cost adsorbents [20] like bark, [21], sawdust, tyre/rubber [22], etc. have the capacity to adsorb toxic metals.

The adsorption process depends on the surface functionalities of adsorbents and generally the groups present in crosslinking agents. It has been reported that the nitrogen-based functional groups like amino, imidazole, amidoxime, and hydrazine groups are more effective regarding the complexation with metal ions compared are to other chelating groups [23–25]. It was also reported that the adsorption of heavy metals from aqueous solutions using modified wastes seems to be a feasible and economical solution [26–29].

In rubber category, styrene-butadiene-styrene (SBS) is a well-known thermoplastic co-polymer (waste) having a block molecular structure. It is a mixture of styrene and butadiene. The styrene and butadiene both have a hydrophobic character, which provides rigidity, strength, and toughness. The adsorption properties depend on the functional groups present in cross-linking agents or it may form bonds with parental polymer, which may enhance the adsorption properties of the adsorbent. Due to this reason, the SBS is nitrated, reduced and then cross-linked with a cross-linking agent, which has more active functional groups for the adsorption of pollutants than original SBS.

In the present study, styrene rubber (SBS) and modified SBS is used for the removal of copper and lead from aqueous solutions. The utilization of rubber for such purposes can accomplish two conclusions. Firstly, as a method of solving a wastewater treatment and secondly use for environmental cleaner.

2. Experimental

2.1. Materials

The SBS, sulphuric acid, and tetrahydrofuran were received from Sigma-Aldrich (Germany). The nitric acid, sodium borohydride and glutaraldehyde hydrochloric acid were obtained from Merck (South Korea).

2.2. Preparation of SBS films

SBS solution was prepared by dissolving 1.5 g SBS in 100 mL of tetrahydrofuran solvent under constant stirring for 1 h at 50°C. In order to obtain a homogeneous solution, the mixture was continuously stirred and then the SBS films/sheets were prepared via casting technique. After complete

evaporation of the solvent, the film was peeled off from the glass plate. The film washed several times with distilled water in order to remove any attached chemicals.

2.3. Chemical activation in SBS membrane

The prepared SBS films are placed in 10 mL nitric acid with the addition of 1–2 drops of sulphuric acid for 2 h. Then the treated SBS membrane was placed in 20 mL of reducing agent (sodium borohydride) for 1 h.

2.4. Preparation of cross-linking SBS membrane

The chemically activated SBS membrane was then placed in a 20 mL cross-linking agent that is, glutaraldehyde for 5 h at 25°C. The chemically modified styrene-butadiene-styrene (CM-SBS) was washed several times with ethanol and distilled water in order to remove any attached cross-linking agent. The CM-SBS was dried and stored for further use.

2.5. Adsorption study

20 mg of SBS and CM-SBS films were taken in various beakers separately, containing 25 mL cations solution with a concentration range from 9.0×10^{-4} to 2.0×10^{-2} mol L^{-1} and stirred for 3 h at room temperature. The adsorbents were removed from the solution after a specific adsorption time. The adsorption study of the remaining solution was analyzed via atomic absorption spectrophotometer.

In kinetics study, 5×10^{-3} mol L^{-1} of a metal solution and 80 mg adsorbent was taken in 1,000 mL beaker at room temperature and stirred for 6 h. The adsorbent was removed from the solution and the adsorbate solution (contain a remaining amount of cations) was analyzed via atomic absorption spectroscopic technique.

The amount of cations adsorbed in mmol g^{-1} was calculated using Eq. (1).

$$N_f = \frac{n_i - n_s}{m} \tag{1}$$

where N_f is the number of moles sorbed on a membrane, n_i is the number of moles in the initial solution, n_s are a number of moles in the supernatant after equilibrium, and m is the mass of the adsorbent used in the experiment.

2.6. Instruments

The surface morphology and elemental percentage of sorbents were studied by scanning electron microscope (SEM) (SM-6490, Joel, Japan) and energy dispersive X-rays (EDX) (JSM 5910) INCA 200/Oxford instrument, UK. The Fourier transform infrared spectrometer (FT-IR) analysis of SBS and CM-SBS was performed by the FT-IR spectrometer (IR prestige-21, FT-IR-8400 Shimadzu, Japan). The pH$_{pzc}$ of the carbons was determined according to the procedure described by Moreno-Castilla et al. [30]. The thermogravimetric analysis (TGA) was done by using Perkin Elmer, USA in an inert atmosphere. The adsorption study was carried out by atomic absorption spectrophotometer (Analyst 700 Perkin Elmer, USA).

3. Results and discussion

3.1. Morphology and EDX study

For surface morphology and to visualize physical state of the surface SEM is an extremely useful technique [31]. Fig. 1 show the surface morphology of SBS and CM-SBS films. The SEM micrograph (Fig. 1a) presents that the surface of neat SBS had non-uniform, rough, dense and with cracks in (film/membrane). The micrograph (Fig. 1b) illustrates that the CM-SBS film had irregular and porous surfaces. The rough and porous surface morphology of CM-SBS might be due to the various processes like nitration, reduction and cross-linking of SBS with glutaraldehyde as partially attached to SBS. It means that the reaction has taken place on the surface.

Table 1 represents the atomic percent of SBS and CM-SBS. The table presented that the content of carbon for the original SBS is 95%, while the CM-SBS had C, N and O are 64%, 17%, and 19%, respectively. It was found that the percent of carbon decreased while amount of nitrogen increase in the case of CM-SBS, which indicated that the nitration and cross-linking process occurred successfully and SBS was chemically modified.

3.2. FTIR study

Fig. 2 presents the FT-IR spectra of SBS and CM-SBS before and after adsorption. The FT-IR spectrum of pure SBS shows peaks at 960; 1,640; and 3,000 cm^{-1}, which might be due to the double bonds of polybutadiene. The peaks appeared at 905, 750, and 700 cm^{-1} is due to phenyl rings of polystyrene units while the peaks at 2,900 and 1,435 cm^{-1} present methyl or methylene groups, respectively. The FT-IR spectrum of CM-SBS showed a broad peak at 3,500 cm^{-1}, which might be due to the presence of the –OH group. The FT-IR spectrum of CM-SBS also showed a peak at 1,638 cm^{-1}, which might be attributed to the ionic interaction between the negatively charged nitrogen group of modified SBS and the positively charged group from crosslinking agent glutaraldehyde. Fig. 2 also illustrated that the intensity of peaks (3,500 and

1,638 cm^{-1}) significantly decreased, which might be due to the adsorption of metals ion onto CM-SBS.

3.3. pH_{pzc} study

The batch equilibrium method for determination of the point of zero charge (PZC) was determined by the same method as discussed somewhere else [32]. The pH of the

Table 1
EDX results of SBS and CM-SBS

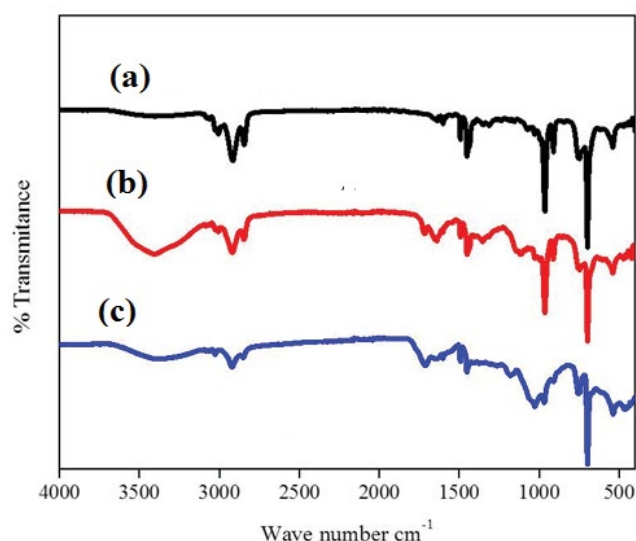|		C	H	N	O
Atomic %	SBS	95%	2%		
	CM-SBS	64%	1%	19%	17%

Fig. 2. FTIR spectra of (a) SBS, (b) CM-SBS (before adsorption), and (c) CM-SBS (after adsorption).

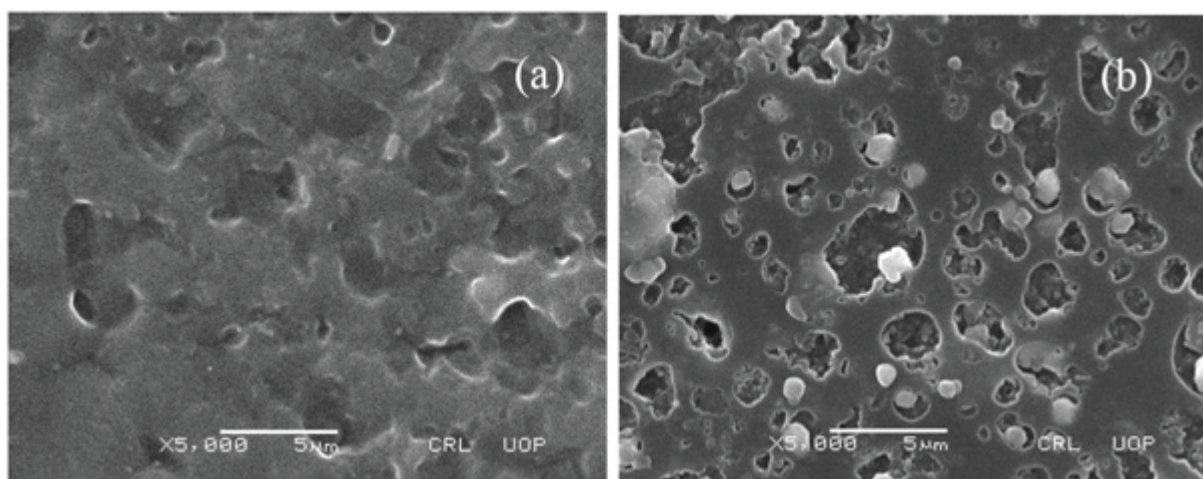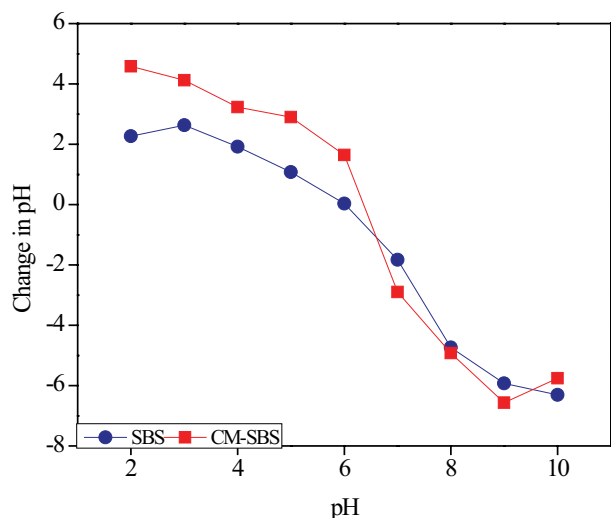
Fig. 1. SEM images of (a) SBS and (b) CM-SBS.

Fig. 3. pH$_{pzc}$ of SBS and CM-SBS membrane.

PZC for a certain surface depends on the relative acidic and basic properties of the solid and permits an assessment of the net uptake of OH$^-$ and H$^+$ ions. The PZC value (Fig. 3) of the SBS was found to be 5.7. It was also found that the values are increased as increased the pH of a medium because more amine groups formed in the case of CM-SBS. The PZC for CM-SBS was determined to be 6.4, which represents the neutral surface (Fig. 3).

3.4. Effect of initial concentration

Figs. 4 and 5 show the effect of initial concentration (0.0009–0.02 mol L^{-1}) on the adsorption of Cu(II) and Pb(II) on SBS and CM-SBS while the other parameters were constant. The result illustrated that CM-SBS adsorbed a high quantity of Cu(II) and Pb(II) as compared to pure SBS, which might be due to rough and porous surface as shown in the SEM micrograph (1b). The amount of adsorbate adsorbed was determined by plotting the adsorbate amount (X) vs. equilibrium concentrations (C_i). The result presented that the adsorption of adsorbate increased as increased the concentration of adsorbate and then an equilibrium is established after 0.004 mol L^{-1} for Cu(II) and Pb(II). It is due to the fact that initially the cations are adsorbed uniformly on the active sites of the adsorbent and after sometime saturation occurs. By further addition of cations there will be no increase in the adsorption process as the non-availability of free active sites for adsorbate molecules [33].

3.5. Effect of pH on the adsorption of metal ions

pH of the solution has a basic role in the adsorption process. The adsorption/uptake capacity of metal ions mainly depends on the pH of a solution, which affects the surface charge of the adsorbent, degree of ionization and the speciation of adsorbates [34,35]. Basically adsorption process happens due to two factors, first the unavailability of amine and aromatic characters for chelation with metals ions due to protonation of amine and aromatic groups. Secondly, there is a
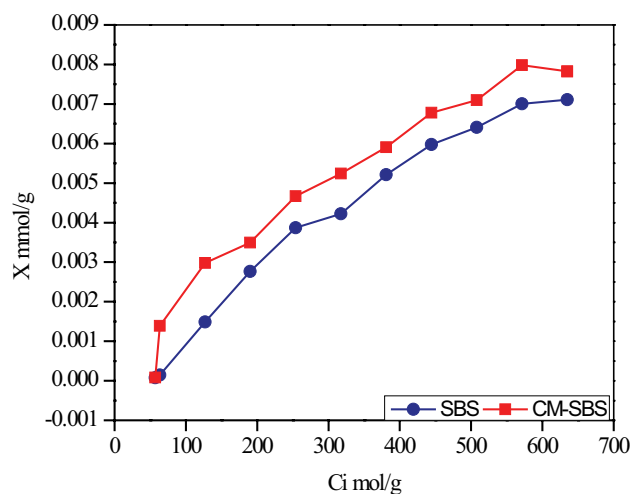

Fig. 4. Effect of the initial concentration of Cu(II) on SBS and CM-SBS, at constant pH 6.0, sorbent dosage, 18 mg and temperature was 25°C.
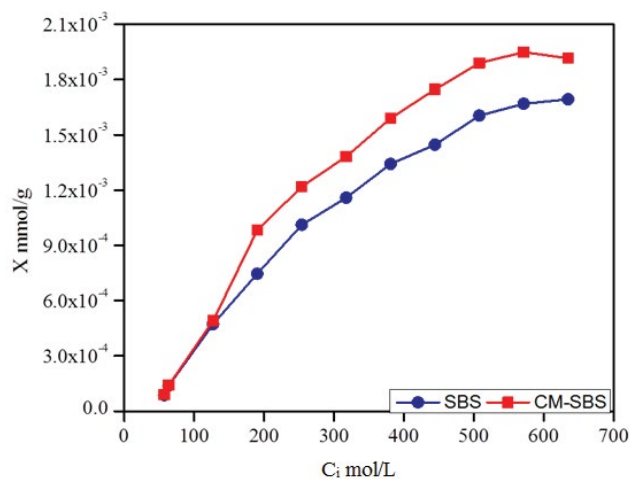

Fig. 5. Effect of the initial concentration of Pb(II) on SBS and CM-SBS, at constant pH 6.0, sorbent dosage, 18 mg and temperature was 25°C.

competition between hydrogen ions (H$^+$) with metal ions for the same binding sites on the adsorbent [36].

Figs. 6 and 7 show the adsorption of Cu(II) and Pb(II) onto SBS and CM-SBS at various pH range 2–12 at constant agitation speed (120 rpm), temperature (25°C), sorbent dosage (18 mg) and initial concentration (127 ppm). The result presented that the adsorption of Cu(II) and Pb(II) increased as increased the pH of solution and then almost level off after pH 7.0 and pH 6.0, respectively. At lower pH, the percent removal of Pb(II) and Cu(II) was very low. Actually, at lower pH, the concentration of H$^+$ ions was high due to which the renewal process was dominated over the adsorption process [36]. Hence, the process of conversion of adsorbent into its H$^+$ form played an important role leaving behind Pb(II) and Cu(II) in the aqueous solution. As the pH increased, the adsorption of Pb(II) and Cu(II) was also increased and maximum adsorption took place at pH 6 and 7. After pH 6 and 7

the adsorption became constant because at pH > 6 and 7, the Pb(II) and Cu(II) precipitated due to the hydroxide anions formed lead hydroxide and copper hydroxide precipitate. The results can also be explained by the point of zero charge (pH$_{pzc}$) of the adsorbents. These values are important with regard to adsorption process because surface characteristics play an important role during the adsorption process [37]. Whenever pH (at which higher adsorption occurred) value higher than pH$_{pzc}$ the surface will carry positive charge and whenever pH value is less than pH$_{pzc}$ surface will carry negative charge. In case of SBS and CM-SBS, the pH$_{pzc}$ values are less than pH for Cu(II) and Pb(II) that is, 5.7, 6.0, 5.9, and 6.8. So, the pH value is higher than PZC. Its means more cations will be removed.
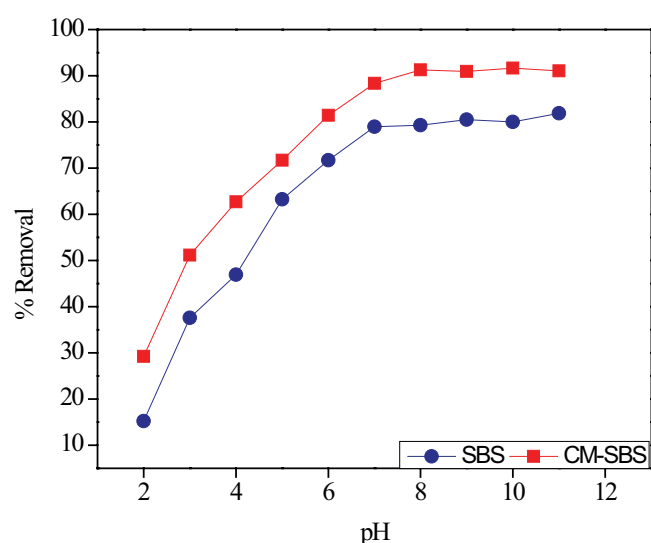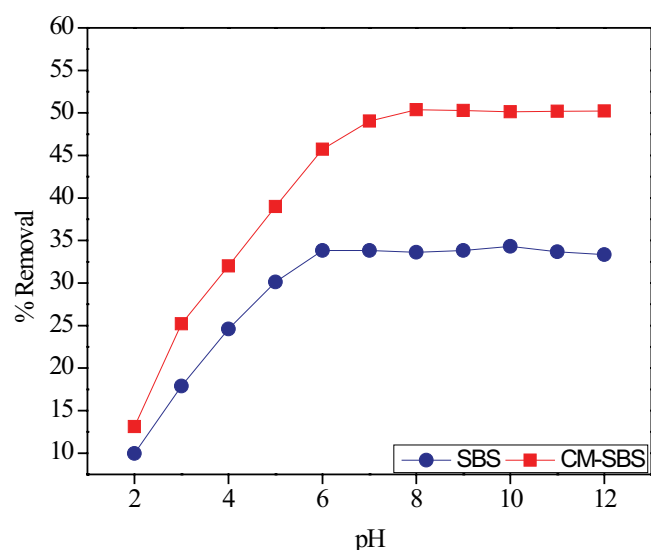
3.6. Effect of contact time

Figs. 8 and 9 show the adsorption kinetic study of Cu(II) and Pb(II) onto SBS and CM-SBS at constant temperature (25°C), adsorbent dose (18 mg), initial pH of the solution (5.9), agitation speed (20 rpm), initial concentration (317 ppm). The results presented that the adsorption of both metal ions were increased as increased the adsorption time and then level off after 100 min. It might be due to availability of more free active sites on both sorbents for cations adsorption and as result adsorption was very high. After 120 min, the adsorption was level off because of decrease of active sites on both sorbents. The results also presented that CM-SBS adsorbed a high quantity of Cu(II) and Pb(II) (0.18 and 0.06 mmol^{-1}) than pure SBS (0.1 and 0.03 mmol g^{-1}), respectively.

Fig. 6. Effect of pH on the adsorption of Cu(II) by SBS and CM-SBS.

Fig. 8. Effect of contact time on the adsorption of Cu(II) by SBS and CM-SBS.
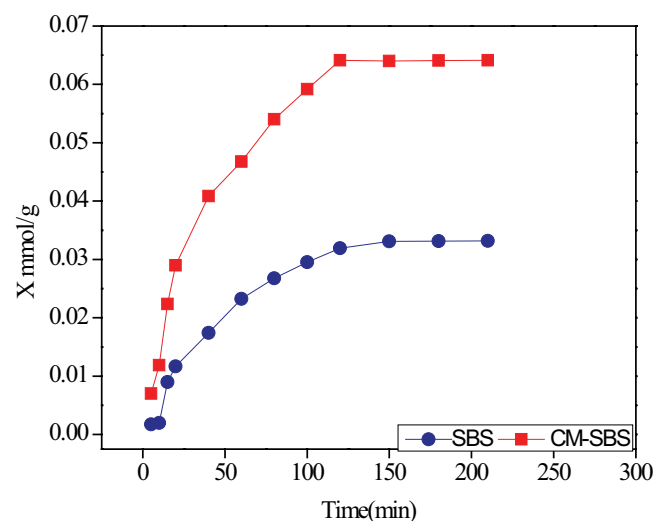

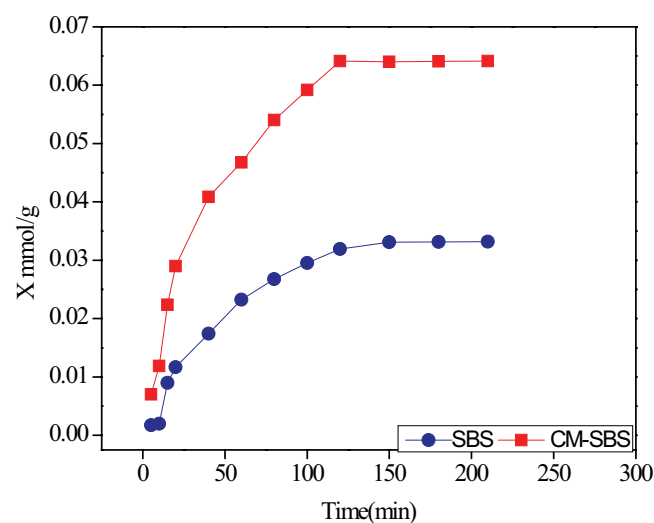Fig. 7. Effect of pH on the adsorption of Pb(II) by SBS and CM-SBS.

Fig. 9. Effect of contact time on the adsorption of Pb(II) by SBS and CM-SBS.

3.7. Adsorption kinetics

Pseudo-first-order and pseudo-second-order rate equations were applied to the data in order to study the mechanism of the adsorption process.

3.7.1. Pseudo-first-order equations

To study the kinetic mechanism of adsorbate in a liquid solution, pseudo-first-order equation is commonly applied, it is generally represented as:

$$\ln(q_e - q_i) = \ln q_e - k_1 t \tag{2}$$

The value of $\ln(q_e - q_i)$ was linearly correlated with t. The graph of $\ln(q_e - q_t)$ vs. t gives straight line and values of k_i and q_e were obtained from the slope and intercept of the graph (Figs. 10 and 11).

3.7.2. Pseudo-second-order equation

The adsorption kinetic rate pseudo-second-order equation is represented as

$$\frac{t}{q_i} = \frac{1}{k_2 q} + \frac{1}{q_e} t \tag{3}$$

A straight line was obtained by plotting t vs. t/q_i where $1/q_e$ represent slope and $1/k_2 q_e$ shows intercept (Figs. 12 and 13). By interpreting the experimental data of pseudo-first-order models and pseudo-second-order models adsorption kinetics mechanism of metals ions by SBS and CM-SBS are shown in Table 2. From X_m (theoretically), X_m (experimentally) and R^2 (correlation coefficient) values, it was confirmed that the pseudo-second-order equation is more applicable as compared to pseudo-first-order kinetic.

3.7.3. Intra-particle diffusion

For porous adsorbents, the diffusion of the adsorbate molecules or ions into the pores is also to be taken into account to find a suitable kinetic model for the process.

Weber and Morris [38] introduced a simple expression to obtain the diffusion rate coefficient (k_i) which was given as:

$$q_i = k_i t^{0.5} + C \tag{4}$$

The values of rate coefficient, k_i (mg g⁻¹ min⁻¹) could be obtained from the slope of the plot, q_t vs. $t^{0.5}$ (Figs. 14 and 15). The values of k_i and C (mg g⁻¹) are summarized in Table 2 along with the correlation coefficient (R^2). The values of R^2 were very low, which suggested that the adsorption of Pb(II) and Cu(II) deviated considerably from the intra-particle diffusion model. If the linear plot passes through the origin, then intra-particle diffusion is the role rate-limiting step. However, the linear plots for SBS and CM-SBS did not pass through the origin, which indicated that the intra-particle diffusion was not only a rate-controlling step.

3.8. Adsorption isotherms

To find out the experimental data many adsorption isotherms have been applied. The most normally used are Langmuir, Freundlich, and Temkin adsorption isotherms.

3.8.1. Langmuir adsorption isotherm

The main assumption of Langmuir adsorption isotherm is that the monolayer adsorption occurs on the surface (homogenous surface) of the sorbent because the sorbate covers the available active site on the surface of the sorbent and then further no adsorption is possible. Representation of Langmuir adsorption isotherm as:

$$\frac{C_e}{X_e} = \frac{1}{K_1 q_m} + \frac{1}{q_m C_e} \tag{5}$$

where X_e is the amount of sorbate sorbed (mg g⁻¹) in equilibrium, C_e (mg L⁻¹) is equilibrium concentration, K_1 (L mg⁻¹) is equilibrium constant and q_m (mg g⁻¹) is total amount of the sorbate required for complete monolayer coverage surface. Figs. 16 and 17 show the Langmuir adsorption isotherm.

Table 2
Kinetic constant parameters obtained for the adsorption of Pb(II) and Cu(II) on to SBS and CM-SBS

| Kinetic models	Parameters	Cu(II) onto SBS	Cu(II) onto CM-SBS	Pb(II) onto SBS	Pb(II) on to CM-SBS
Pseudo-first-order	$X_{m(exp)}$	0.0067	0.0068	0.0019	0.001
	$X_{m(theo)}$	0.3681	0.3334	0.3334	0.6295
	K_1	−0.6033	−0.9027	0.0069	−0.0069
	R^2	0.573	0.478	0.877	0.821
Pseudo-second-order	$X_{m(exp)}$	0.0067	0.001	0.0019	0.001
	$X_{m(theo)}$	0.003	0.001	0.008	0.004
	K_2	−2,022.64	−1,715.5	9.643	−8.928
	R^2	0.929	0.94	0.953	0.950
Intra-particle diffusion	K_1 (mg g⁻¹ min⁻¹)	3.52×10^{-4}	6.94×10^{-4}	1.58×10^{-4}	2.27×10^{-4}
	C (mg g⁻¹)	0.071	0.10	0.01	0.004
	R^2	0.69	0.43	0.81	0.62
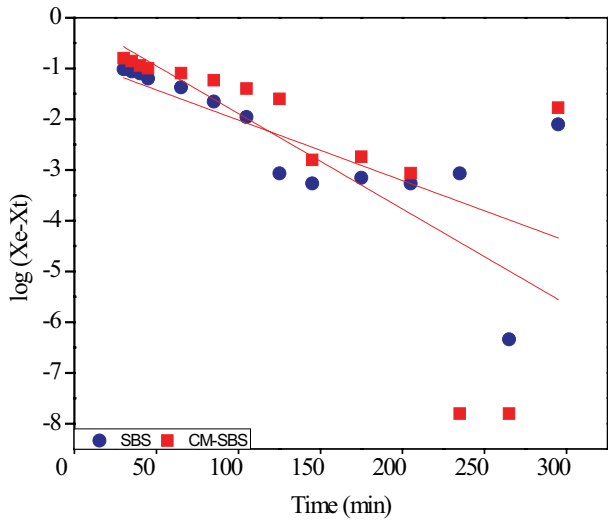
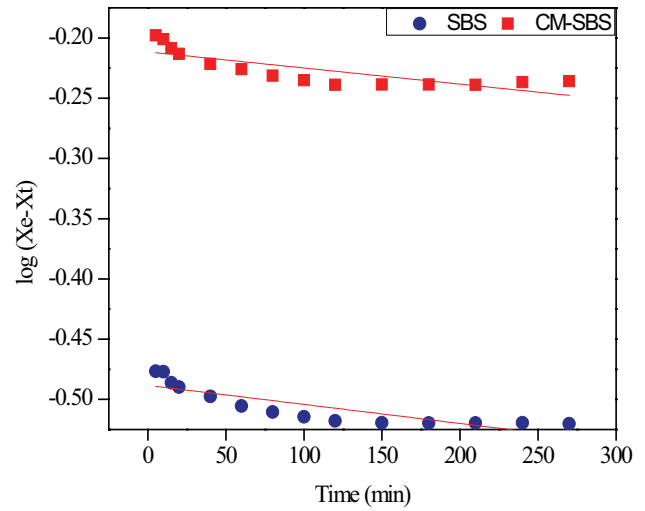Fig. 10. Pseudo-first-order kinetics for Cu(II).

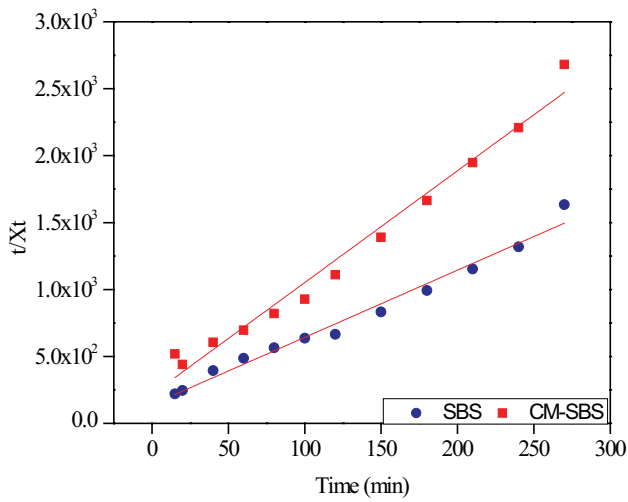
Fig. 11. Pseudo-first-order kinetics for Pb(II).

Fig. 12. Pseudo-second-order kinetics for Cu(II).
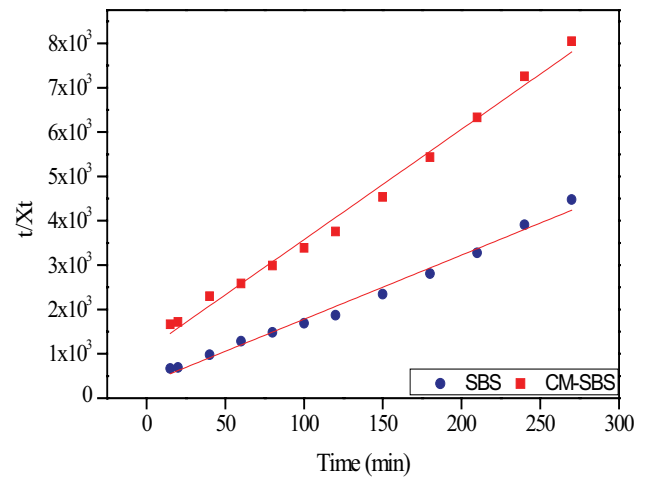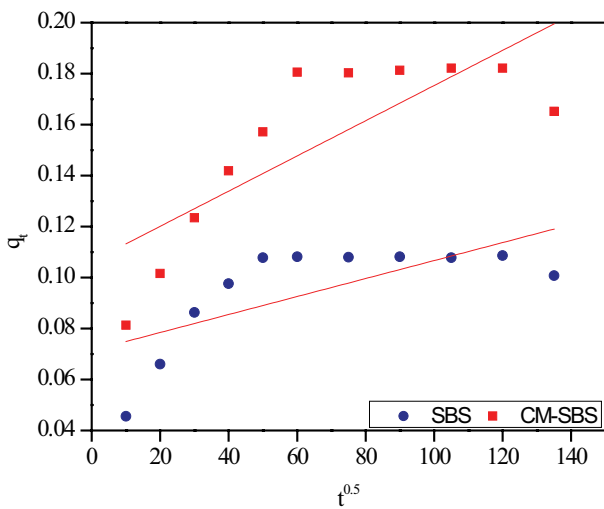

Fig. 13. Pseudo-second-order kinetics for Pb(II).

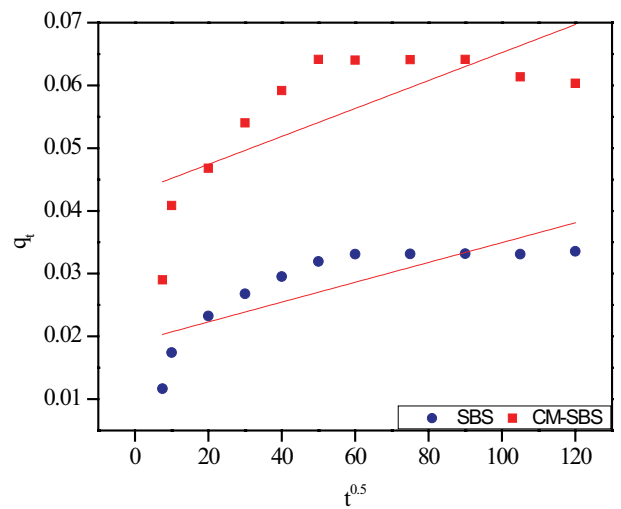Fig. 14. Intra particle diffusion model for Cu(II).

Fig. 15. Intra particle diffusion model for Pb(II).

3.8.2. Freundlich adsorption isotherm

Freundlich isotherm is commonly representing the multi-layers adsorption. The Freundlich adsorption isotherm model also suggests monolayer adsorption with a heterogeneous distribution of the functional groups [39]. The Freundlich adsorption isotherm as:

$$\frac{X_a}{X_m} = K_f C \frac{1}{n} \tag{6}$$

where K_f is the Freundlich constant, C is the concentration (mg L^{-1}), n is adsorption intensity, and X_a/X_m is the amount of adsorbate adsorbed at equilibrium (mg g^{-1}). The Freundlich isotherm is shown in Figs. 18 and 19.

3.8.3. Temkin adsorption isotherm

For the interaction between adsorbate and adsorbent, another isotherm known as Temkin isotherm [40] is used.

By coverage of adsorbate, the heat of adsorption of all molecules would decrease linearly by adsorbate–adsorbent interactions, providing that the concentration will be neither very high nor very low. This adsorption isotherm is characterized by equally distribution of binding energies.

The mathematical forms of Temkin adsorption isotherm as:

$$X_e = A - B \ln C_e \tag{7}$$

$$A = \frac{RT \ln K_t}{b} \tag{8}$$

where A, B and b an intercept, slope, and $b =$ is Temkin constant, respectively. A plot of X_e vs. $\ln C_e$ gives us b and K_t values. The constant b is heat of adsorption. Table 3 shows the high value of b provided the heat of adsorption for the metal ions on SBS and CM-SBS showed a strong interaction between adsorbent surface and heavy metal ions, where maximum binding energy is represented by equilibrium binding constant K_t. The Temkin adsorption isotherm is
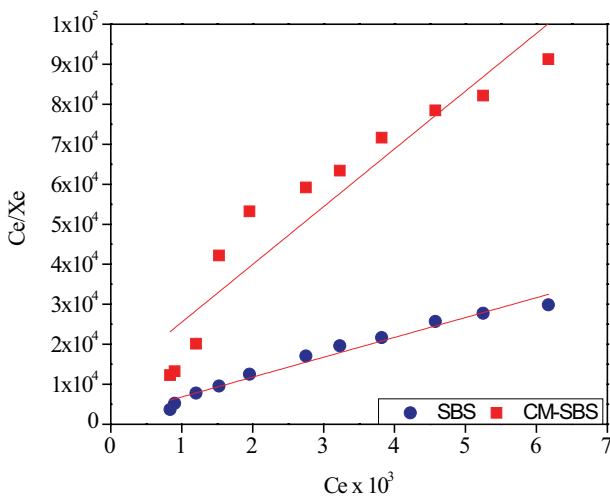

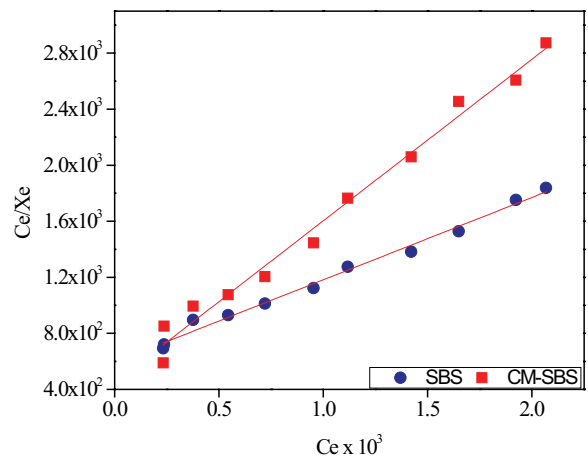Fig. 16. Langumir isotherm for Cu(II).

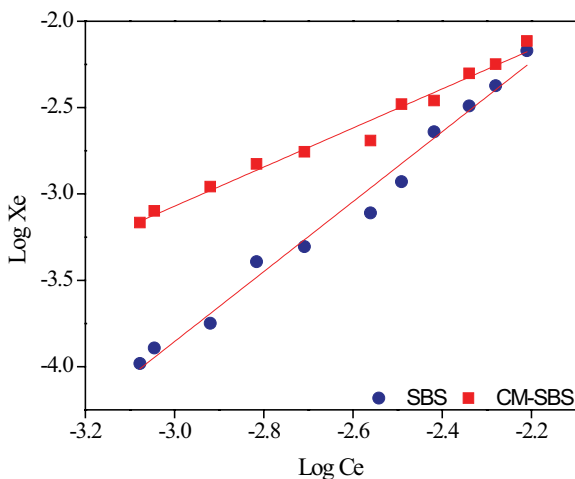
Fig. 17. Langumir isotherm for Pb(II).
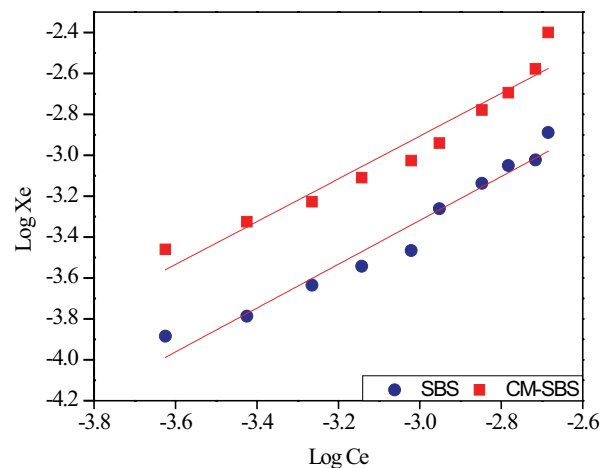

Fig. 18. Freundlich isotherm for Cu(II).

Fig. 19. Freundlich isotherm for Pb(II).

Table 3
Langmuir, Freundlich and Temkin isotherms constants for the adsorption of Pb(II) and Cu(II) onto SBS and CM-SBS

	Langmuir isotherm constant			Freundlich isotherm constants			Temkin isotherm constant		
	X_m	K_L (mol L^{-1})	R^2	K_f	N	R^2	K_t	B (mol Kg^{-1})	R^2
Cu(II)									
SBS	0.108	–0.098	0.99	6.025×10^{-5}	5.319	0.992	0.449	268.43	0.968
CM-SBS	0.182	2.38	0.96	5.24×10^{-4}	9.523	0.991	0.541	255.5	0.984
Pb(II)									
SBS	0.033	4.178	0.977	2.0×10^{-4}	9.09	0.997	7.033	256.7	0.981
CM-SBS	0.064	0.935	0.973	7.5×10^{-5}	8.695	0.994	1226.4	1.054	0.965

Table 4
Comparison of maximum multilayer adsorption capacity of Pb(II) and Cu(II) ions using various adsorbents

Metal ions	Adsorbents	Value of N	References
Pb(II)	Ti(IV) iodovanadate cation exchanger	1.4	[36]
	Ash	6.63	[41]
	Fe nanoparticles loaded ash	5.12	[41]
	Surfactant assisted nano-composite cation exchanger	1.9	[42]
	EDTA modified *Artocarpus odoratissimus* leaves	3.7	[43]
	Peat collected from Brunei Darussalam	3.7	[44]
	SBS	5.3	Present work
	CM-SBS	9.5	Present work
Cu(II)	Mumong peat	3.5	[45]
	Panaga peat	1.7	[45]
	expanded perlite	3.31	[46]
	Chitosan cross-linked with epichlorohydrin-triphosphate	2.6	[47]
	SBS	9.0	Present work
	CM-SBS	8.6	Present work

Table 5
Comparison of adsorption capacities of different adsorbents

Metal ions	Adsorbents	q_{max} (mg g^{-1})	Ref.
Cu(II)	SBS	6.3	Present work
	CM-SBS	11.4	Present work
	Mumong peatt	16.5	[44]
	Panaga peat	14.6	[44]
	Banana peel	3.6	[48]
	Orange peel	3.6	[48]
	Sugarcane bagasse	3.7	[49]
	Coconut tree sawdust	3.9	[49]
Pb(II)	SBS	6.2	Present work
	CM-SBS	12.4	Present work
	Chitosan-coated sand	12.3	[50]
	Expanded perlite	13.3	[46]
	Lichen (*Cladonia furcata*) biomass	7.9	[51]
	Bacterially produced metal sulfides	14.4	[52]
	Crosslinked metal-complexed chitosans	14.0	[53]
	Natural kaolinite clay	2.3	[54]

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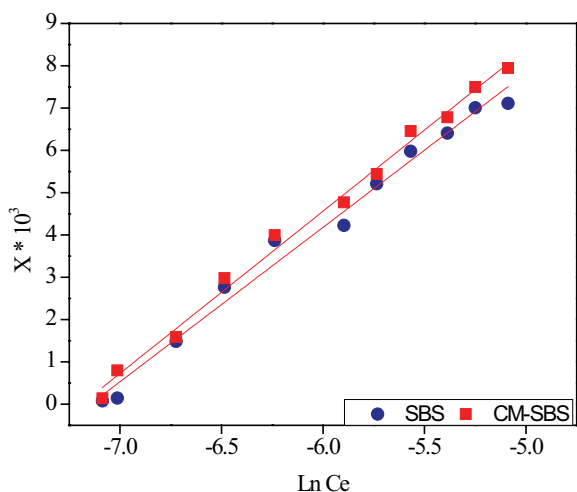

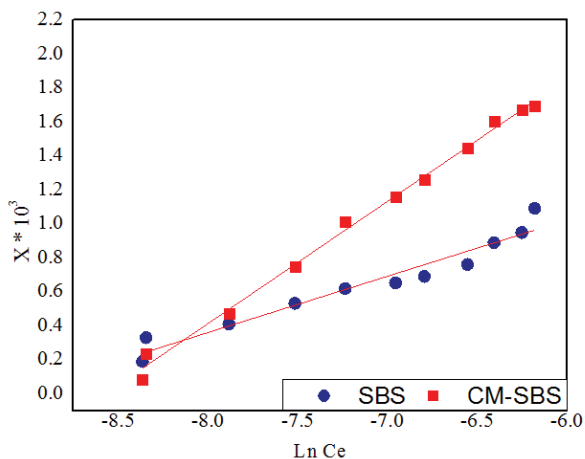Fig. 20. Temkin isotherm for Cu(II).

Fig. 21. Temkin isotherm for Pb(II).

shown in Figs. 20 and 21. The comparative study of the SBS and CM-SBS with other adsorbents are presented in Tables 4 and 5.

4. Conclusion

It was concluded that the SBS was successfully modified chemically. The morphological study presented that the surface of CM-SBS is rough/porous as compared to pure SBS. Both CM-SBS and neat SBS films showed strong affinity toward the heavy metals. It was also found that the adsorption capacity of CM-SBS was higher than neat SBS film. It was also observed that the Freundlich model present best result than Langmuir and Temkin isotherms.

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