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## ORIGINAL ARTICLE

# **Removal of Hg (II) and Mn (II) from aqueous** solution using nanoporous carbon impregnated with surfactants



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#### **KEYWORDS**

Surfactant; Mesoporous carbon; Mercury and manganese; Adsorption; Langmuir and Freundlich isotherm Abstract Mesoporous carbons were impregnated with the anionic and cationic surfactants to increase adsorbing capacity for heavy metal ions. Prepared samples were characterized by X-ray diffraction (XRD) and nitrogen adsorption-desorption isotherms. Batch adsorption studies were carried out to study the effect of various parameters like contact time, pH, metal ion concentration and agitation speed. The mercury removal by cationic surfactant cetyltrimethyl ammonium bromide (CTAB), anionic surfactant sodium dodecyl sulfate (SDS) modified mesoporous carbon and unmodified mesoporous carbon were found to be 94%, 81.6% and 54.5%, respectively while the manganese removal for these adsorbents were found to be 82.2%, 70.5% and 56.8%, respectively. The sorption data were fit better with the Langmuir adsorption isotherm than Freundlich isotherm. © 2011 Production and hosting by Elsevier B.V. on behalf of King Saud University. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/3.0/).

#### 1. Introduction

Heavy metals are toxic to aquatic flora and fauna even in relatively low concentrations. Some metals can be assimilated, stored and accumulated in organisms (Mohan et al., 2006; Mohan and Singh, 2002). Removal of toxic heavy metal ions from the environment is an important challenge. Ideally, a

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removal process must be simple, effective and inexpensive. To remove heavy metal ions from wastewaters, several processes have been employed heretofore including chemical precipitation and ion exchange (Dean et al., 1972), coagulation and flocculation (Amuda et al., 2006), complexation, biosorption (Park et al., 2007) and membrane process (Aydiner et al., 2006).

Minamata and autism diseases (Kurtland et al., 1960) exposed to  $Hg^{2+}$  can have harmful effects on reproduction, the central nervous system, liver and kidney. It can also cause sensory and psychological impairments (Merrifield et al., 2004). Environmental Protection Agency (EPA) to water quality standards promulgated under the Safe Drinking Water Act is 0.002 mg Hg/L.

Manganese is a quite abundant metal in the earth crust and its presence in groundwater is due to leaching processes and varies widely depending on the rock types. Also, manganese

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has a variety of applications such as in metallurgical processes, mining, ceramics, dry cell batteries, pigments and paints which all can be the sources of underground pollution (Chang et al., 2009). At low levels, it presents as  $Mn^{2+}$  in the soil and is a nutrient essential for all crops, while it is toxicant in the range of 0.1–0.5 mg/L (Rajic et al., 2009; Horst and Marschner, 1978). However, there are very limited studies on the sorption of Mn (II) ions by various available sorbents (Nassar, 2006). The SMCL (secondary maximum contaminant levels) recommended by the EPA for drinking water is 0.05 mg Mn/L.

Adsorption processes are generally known to be one of the most effective techniques for removal of environmentally hazardous metals. Several materials such as activated carbon (Starvin and Rao, 2004; Zhang et al., 2005), resins (Yavuz et al., 2005; Atia et al., 2005) and clavs Tonle et al., 2003; Manohar et al., 2002 have been studied for adsorption of Hg (II) ions. Recently, Ryoo et al. prepared ordered mesoporous carbons (CMK-x) from mesoporous silica templates such as MCM-48, SBA-1 and SBA-15 using sucrose as the carbon source (Ryoo et al., 1999, 2001; Jun et al., 2000; Anbia and Lashgari, 2009; Anbia and Ghaffari, 2009; Anbia and Moradi, 2009; Anbia et al., 2010). Adsorption capacity of mesoporous carbon materials depends on different factors. Obviously, it depends on the characteristics of mesoporous carbon such as texture (surface area, pore size distributions) and surface chemistry (surface functional groups) (Bansal et al., 1988; Gregg and Sing, 1982; Radovic et al., 1997). It also depends on adsorptive characteristics: molecular weight, polarity, pK<sub>a</sub>, molecular size and functional groups of adsorbates.

To enhance adsorption efficiency and adsorption reaction and to decrease consumption of adsorbent, the surface of the adsorbent is modified. Surface-active substances or surfactants are amphipathic substances with lyophobic and lyophilic groups making them capable of adsorbing at the interfaces between liquids, solids and gases.

The objectives of this study were thus to investigate the effect of surfactant modification on the structural morphology and surface area of indigenously produced mesoporous carbon. This was accomplished by evaluating the Hg (II) and Mn (II) removal efficiency by analyzing the sorption data fitting them in Langmuir and Freundlich models.

#### 2. Experimental

#### 2.1. Materials

Reagents used in this study were tetraethyl orthosilicate (TEOS, 98%) as a silica source,  $EO_{20}PO_{70}EO_{20}$  (Pluronic P123) as a surfactant, sucrose as a carbon source, sulfuric acid as a catalyst for synthesis of mesoporous carbon, HCl and deionized water for synthesis of mesoporous silica (SBA-15). Surfactants used were the cationic surfactant cetyltrimethyl-ammonium bromide (CTAB,  $C_{16}H_{33}NCH_3Br$ ) anionic surfactant sodium dodecyl sulfate (SDS,  $CH_3(CH_2)_{11}SO_4^-Na^+$ ) for surface modification. Metal ions solutions for adsorption experiments were prepared by dissolving Hg (II) nitrate monohydrate 98% in dilute HNO<sub>3</sub> (1 M) and MnSO<sub>4</sub> in deionized water. All chemicals were analytical grade and obtained purchased from Merck (Darmstadt, Germany) except Pluronic® P123 and Hg (II) nitrate monohydrate were from Aldrich and were used without further purification.

#### 2.2. Synthesis of mesoporous carbon MC

Mesoporous carbon was synthesized using SBA-15 (Zhao et al., 1998) as template according to the previously reported procedure (Jun et al., 2000). In brief, SBA-15 sample was prepared using the triblock copolymer, Pluronic P123 as the surfactant and tetraethylorthosilicate (TEOS) as the silica source according to synthesis procedure reported in reference (Zhao et al., 1998) by first heating the reaction mixture at 40 °C for 4 h, followed by aging at 100 °C for 24 h. The calcined SBA-15 sample was further used as template for the synthesis of mesoporous carbon. Sucrose was introduced and polymerized inside SBA-15 with H<sub>2</sub>SO<sub>4</sub> as catalyst according to reference (Jun et al., 2000) and carbonization in N<sub>2</sub> atmosphere by heating to 900 °C with a rate of 2 °C/min. The template was removed by washing the sorbent (SBA-15) with 1 M solution of NaOH in 1:1 EtOH-H2O mixture (twice) at 90 °C in order to dissolve the silica template completely. After removal of the silica, the carbon samples were filtered, washed with ethanol and dried at 120 °C.

#### 2.3. Modification with surfactants

Modification was carried out by treating 5 g of adsorbent with 100 mL solution of each cationic and anionic surfactant, respectively at respective CMCs. All the samples were placed in a temperature controlled shaker with 180 rpm, at  $70 \pm 0.5$  °C for 420 min and left to attain the ambient conditions. Each sample was filtered by Whatman-42 paper filter without rinsing, and dried overnight in an oven at 110 °C (Nadeem et al., 2009).

#### 2.4. Characterization

The X-ray diffraction (XRD) analysis was utilized to identify the crystallinity of the SBA-15 samples. The XRD patterns were recorded with a Philips 1830 powder X-ray diffractometer using Cu-K $\alpha$  radiation source of wavelength 1.5406 for 2 h ranging from  $0.8^{\circ}$  to  $6.0^{\circ}$  with a  $2\theta$  step size of  $0.01^{\circ}$  and a step time of 1 s. Adsorption-desorption isotherms of the synthesized samples were measured at 77 K on micromeritics model ASAP 2010 sorptometer to determine an average pore diameter. Residual Hg (II) and Mn (II) concentrations were analyzed by inductively coupled plasma-optical emission spectroscopy (ICP-OES) on a SHIMADZU ICPS-7000.ver2 instrument (Nebulizer: Coaxial type, made of Pyrex glass; Detector: CCD array detector). Triplicate runs of each test were conducted and the obtained data vary within 5% suggesting the accuracy of the results. The metal concentration retained by the adsorbent phase was calculated using the following relation.

#### 2.5. Adsorption studies

Two stock solutions of analytes (Hg (II): 200 mg  $L^{-1}$ , Mn (II): 500 mg  $L^{-1}$ ) were prepared in deionized doubly distilled water using Hg (II) nitrate monohydrate and Mn (II) sulfate as the analyte sources. All working solutions of varying concentrations were obtained by successive dilutions. 0.1 N HCl and 0.1 N NaOH solutions were used for pH adjustments. All sample volumes in the batch adsorption experiments are 50 mL.

The amount of analyte adsorbed by adsorbents  $(q_e)$  in the sorption system was calculated using the mass balance:

$$q_e = (C_o - C_e) \frac{V}{m} \tag{1}$$

where  $q_e$  is the equilibrium adsorption capacity (mg g<sup>-1</sup>),  $C_{\circ}$  and  $C_e$  are initial and equilibrium concentrations of analyte in the solution (mg L<sup>-1</sup>) respectively, V is the volume of solution taken (L), and m is the mass (g) of adsorbent used.

#### 3. Results and discussion

#### 3.1. Characterization of surfactant modified mesoporous carbons

The quality of the mesoporous carbon samples prepared in this study was examined using nitrogen adsorption-desorption analysis and X-ray diffraction (XRD) technique. Nitrogen physisorption is a common method to gain knowledge about mesoporous materials. This method provides information on the specific surface area and the pore diameter. Calculating pore diameters of mesoporous materials using the BJH equation is a usual method, moreover former studies showed that the application of the BJH gives appropriate qualitative results which allows a direct comparison of relative changes between different mesoporous materials. The nitrogen sorption isotherms of the carbonaceous adsorbents, having the typical type IV shape are illustrated in Fig. 1. The pore size distributions were essentially the same as before surfactant modification. The adsorption uptakes at relative pressure close to  $p/p^{\circ} = 0$ were also identical (Fig. 1). However, the total uptakes were slightly different; increasing with the surface modification with surfactants (Table 1). Each isotherm showed a distinct hysteresis loop, which is characteristic of mesoporous adsorbents (Gregg and Sing, 1982; Radovic et al., 1997). This phenomenon is associated with capillary condensation in mesopores. Pores within porous materials are classified as micropores (<2 nm), mesopores (2-50 nm), and macropores (>50 nm), in accordance with the classification adopted by the IUPAC (Sing et al., 1985). In the case of the prepared samples, since



**Figure 1** Adsorption–desorption isotherms of nitrogen at 77 K on MC, CTAB–MC, SDS–MC.

 Table 1
 Textural properties determined from nitrogen adsorption-desorption experiments at 77 K.

Adsorbent	d spacing (nm)	$A_{BET}~(m^2~g^{-1})$	$Vp (cm^3 g^{-1})$
MC	4.1	1179.2	1.32
CTAB-MC	3.6	1193.9	1.2
SDS-MC	3.7	1198.4	1.14

the large peaks at pore diameters are greater than 2 nm all the pore size distribution curves suggested that mesopores were predominant. The modification led to an increase in the total uptake of the modified carbons (was the result of the presence of porosity in the surfactants that has loaded on the surface of mesoporous carbon adsorbents), which increased the total pore volume of the prepared samples. The modified mesoporous carbons essentially kept the bimodal pore size distribution, which is characteristic of the parent MC. The textural parameters listed in Table 1 clearly confirm the structural changes of modified MC.

The XRD powder patterns of carbonaceous adsorbents were obtained on Philips 1830 diffractometer using Cu-Ka radiation of wavelength 0.154 nm (Fig. 2). The XRD patterns of the un-treated MC showed a strong (100) peak and proportional (110) and (200) peak intensities and the observed data are in good agreement with that previously reported (Jun et al., 2000). The XRD patterns of carbon and modified mesoporous carbons (Fig. 2) showed well-resolved reflections indicating that MC fairly maintained its original structure even after the modification by surfactants. In the case of modified mesoporous carbon samples, the hexagonal structure of MC was maintained well, but the XRD reflections became less pronounced that might be attributed to the partial damage of the mesoporous (hexagonal) structure or due to the decreased contrast between walls and pores because of the cleavage of the carbon species from the pore walls.

## 3.2. Distribution of Hg (II) and Mn (II) species and effect of pH

Theoretically, Hg (II) ions in solution exist as different species depending on the pH of the solution. A distribution diagram (Fig. 3) was calculated based on literature data (Nazarenko et al., 1979) on the stability constants for Hg(OH)<sup>+</sup>, Hg(OH)<sub>2</sub> and Hg(OH)<sub>3</sub><sup>-</sup> and a total concentration of mercury ions of  $1 \times 10^{-4}$  mol L<sup>-1</sup>. The effect of pH on the proportion of mercury species present was determined at  $1 \times 10^{-4}$  M of ionic



Figure 2 XRD patterns of MC, SDS-MC and CTAB-MC.



**Figure 3** Distribution of mercury species in aqueous system as a function of pH.

strength at 20 °C (Fig. 3). In this study, we conducted all batch adsorption experiments for mercury at  $pH \le 6$ .

Mercury ion speciation is affected by solution pH through the following equilibrium (Babi et al., 2002):



**Figure 4** Effect of pH on (a) mercury ion and (b) manganese ion removal over MC, CTAB-MC and SDS-MC as adsorbent  $([Hg^{2+}] = 10 \text{ mg L}^{-1}, [Mn^{2+}] = 50 \text{ mg L}^{-1}$ , adsorbent dose =  $1 \text{ g L}^{-1}$ , temperature =  $25 \pm 1 \text{ °C}$ ).

$$Hg^{2+} + OH^- \leftrightarrow Hg(OH)^+, \quad pK_1 = 3.5$$
 (2)

$$\mathrm{Hg(OH)}^{+} + \mathrm{OH}^{-} \leftrightarrow \mathrm{Hg(OH)}_{2}, \quad \mathrm{pK}_{2} = 4.0 \tag{3}$$

$$Hg(OH)_2 + OH^- \leftrightarrow Hg(OH)_3^-, \quad pK_3 = 14.8$$
<sup>(4)</sup>

Hydrated precipitate of manganese,  $Mn(OH)_2$ , is formed at pH > 8, consequently the adsorption measurements were conducted below this pH (Smiley et al., 1986).

#### 3.3. Effect of pH

The adsorptions of mercury and manganese ions on unmodified and modified mesoporous carbon as a function of pH are given in Fig. 4. The adsorption of mercury ions was insignificant at pH 3 and increased sharply in pH range between 3 and 6, reaching a maximum value at pH 6. The highest recoveries were achieved at pH 6 for mercury ions with the modified and the unmodified mesoporous carbon sorbents. For Mn (II) uptake, almost no significant changes appeared between pH 2 and 4, but a rapid increase was observed at pH higher than 4 and finally the highest adsorption was achieved at pH 7. Higher pH values were avoided to prevent possible precipitation as hydroxides (Nazarenko et al., 1979).

The effect of pH can be explained in terms of electrostatic interactions initiated by the adsorbent. At lower pH, the surface charge of the adsorbent is positive which is similar to



**Figure 5** Effect of contact time on removal of (a) mercury ion and (b) manganese ion  $([Hg^{2+}] = 10 \text{ mg } L^{-1}, [Mn^{2+}] = 50 \text{ mg } L^{-1}$ , adsorbent dose = 1 g L<sup>-1</sup>, temperature = 25 ± 1 °C).



Figure 6 Effect of initial concentration on removal of Hg (II) and Mn (II) (amount of SDS-MC =  $1 \text{ g L}^{-1}$ , agitation speed = 200, temperature =  $25 \pm 1 \text{ °C}$ ).

the predominant metal species in the solution. Therefore, the removal of metals in the pH range of 3–4 is low because of the less inclination of the metal species to migrate to the adsorbent because of like-charges repel. As the pH becomes less acidic (higher pH), there is a greater possibility for the positive metal ions to be attracted to increasingly negatively charged adsorbents. Moreover, there are also possible sites on carbonaceous surface for specific adsorption of H<sup>+</sup> ions that can be exchanged with the cations in the solution. The reduction in manganese removal beyond pH 8 (i.e. toward more basic pH condition) may be attributed to the possible precipitation of Mn(OH)<sub>2</sub> occupying the adsorption sites, preventing further removal of Mn (II) via adsorption.

#### 3.4. Effect of contact time and concentration

In order to study equilibration time for maximum uptake and to know the kinetics of adsorption process, the adsorption of mercury and manganese on carbonaceous adsorbent was studied as a function of contact time and results are shown in Fig. 5. This Figure indicates that the time required for equilibrium adsorption is around 250 min. Thus, for all equilibrium adsorption studies, the equilibration period was kept 300 min. The effect of concentration on the equilibration time was also investigated as a function of initial mercury and manganese concentration and the results are shown in Fig. 6.

At lower initial metal concentrations, sufficient adsorption sites are available for the sorption of metal ions. Conversely, the numbers of metal ions at higher initial concentrations are



**Figure 7** Effect of agitation speed on the adsorption percent of SDS-MC adsorbent ( $[Hg^{2+}] = 10 \text{ mg } L^{-1}$ ,  $[Mn^{2+}] = 50 \text{ mg } L^{-1}$ , adsorbent dose = 1 g L<sup>-1</sup>, temperature = 25 ± 1 °C).

relatively more as compared to the available adsorption sites. Hence, the percentage of metal ions removal correlates inversely with the initial metal concentration.

#### 3.5. Effect of agitation speed

The effect of agitation speed on removal efficiency of Hg (II) and Mn (II) on SDS-MC was studied varying the speed of agitation from 50 to 250 rpm, while keeping the analyte concentration, contact time, pH, temperature and dose of the adsorbent as constant. As it is demonstrated in Fig. 7, increasing agitation speed from 50 rpm to 200 rpm increased the efficiency of metal ions removal and the adsorption capacity of carbonaceous adsorbent remained constant for agitation rates greater than 200 rpm. These results can be associated to the fact that the increase of the agitation speed, improves the diffusion of analyte into the pores of the adsorbents. This also indicates that a shaking rate in the range 200-250 rpm is sufficient to assure that the maximum available sites of adsorbent existing in the pores of adsorbents are made readily available for Hg and Mn uptakes. For convenience, agitation speed of 200 rpm was selected as the optimum speed for all the adsorption experiments.

#### 3.6. Effect of surfactant modification

Results of surfactant-treatment carried out on the adsorbents are shown in Fig. 5 and 6. Hg (II) removal percentages of 94, 81.6 and 54.5% and Mn (II) removal percentages of

Analyte	Adsorbent	Langmuir			Freundlich		
		$q_m (\mathrm{mg}\mathrm{g}^{-1})$	$b (L mg^{-1})$	$R^2$	$K_f (\mathrm{mg g}^{-1})$	$n (\mathrm{L mg}^{-1})$	$R^2$
Hg (II)	MC	7.4	0.09	0.991	10.2	1.18	0.938
	CTAB-MC	8.1	0.1	0.990	14.5	1.32	0.966
	SDS-MC	8.9	0.13	0.995	17.6	1.67	0.947
Mn (II)	MC	40	0.008	0.991	24.3	6.23	0.928
	CTAB-MC	43	0.02	0.990	29.6	7.44	0.922
	SDS-MC	47	0.022	0.987	33.9	7.72	0.919

Table 2 Langmuir parameters for the sorption of Hg (II) and Mn (II) at pH 6 and 7, respectively on carbonaceous adsorbents

Adsorbate	Adsorbent	Initial concentration (ppm)	$q_e \ ({ m mg/g})$	Adsorption percentage	References
Hg (II)	(GCA)	200	82	20.5	Chang et al., 2009
	MCM-41-NH-L	20	152	98	Puanngam and Unob, 2008
	Silica gel	100	140	78	Puanngam and Unob, 2008
	SDS-MC	10	8.9	94	Present study
	CTAB-MC	10	8.1	81.6	Present study
	MC	10	7.4	54.5	Present study
Mn (II)	Zeolite Na-CLI	400	8.7	21.7	Rajic et al., 2009
	NH2-MCM-48	55	4.5	41.3	Yang et al., 2008
	NH2-SBA-15	110	8.7	39.6	Yang et al., 2008
	SDS-MC	50	47	82.2	Present study
	CTAB-MC	50	43	70.5	Present study
	MC	50	40	56.8	Present study

 Table 3
 Comparison of adsorption capacity and adsorption percentage of Hg (II) and Mn(II) onto various adsorbents.

82.2, 70.5, and 56.8 were achieved using SDS, CTAB-treated and untreated mesoporous carbon adsorbent, respectively. All surfactants showed a pronounced effect regarding to their efficiency in terms of percentages of Hg (II) and Mn (II) removal. The maximum percentage of removal was observed by SDS-treated mesoporous carbon adsorbent for both adsorbate correlates well with the finding discussed in Fig. 1 and Table 1.

High adsorption efficiency of SDS–MC could be due to electrostatic interactions between positive metal species and negative head of the anionic SDS surfactant. On the other hand, the ability of surfactant to accelerate the removal efficiency of toxic, noble and rare metals has been attributed to the wetting characteristic and/or micellar solubilization (Rosen, 2004). As a consequence of functionalization, the CTAB–MC sorbent would have positive surface charge and would be able to adsorb metal ions on its surface due to electrostatic interactions. This is in addition to the usual adsorption of the ions inside the pores. Therefore, the functionalized sorbent would show higher performance than the untreated MC, as reflected in Figs. 5 and 6. Moreover, carbon surfaces have both negative (anionic) and positive (cationic) functional groups to attract free ions in solution or suspension.

#### 3.7. Isotherms studies

The adsorption processes of Hg (II) and Mn (II) were tested with Langmuir and Freundlich isotherm models. Isotherm parameters for the Freundlich and Langmuir models for modified and unmodified carbon adsorbents are given in Table 2. Two commonly used empirical adsorption models, Freundlich and Langmuir which correspond to heterogeneous and homogeneous adsorbent surfaces respectively, were employed in this study. The Freundlich and Langmuir model are given by the Eqs. (5) and (6), respectively (see Fig. 7).

$$\ln q_e = \ln K_f + \left(\frac{1}{n}\right) \ln C_e \tag{5}$$

$$\frac{C_e}{q_e} = \left(\frac{1}{q_m b}\right) + \left(\frac{1}{q_m}\right)C_e \tag{6}$$

where  $q_e \pmod{g^{-1}}$  is the amount of adsorbates adsorbed per gram of carbonaceous adsorbents at equilibrium;  $C_e \pmod{L^{-1}}$  is the equilibrium concentration of adsorbates in the solution;

 $K_f$ , is a Freundlich isotherm constant for the system and the slope 1/n, ranging between 0 and 1, indicative of the degree of nonlinearity between solution concentration and adsorption;  $q_{\rm m} \ ({\rm mg g}^{-1})$  is the maximum monolayer adsorption capacity and  $b \ ({\rm L mg}^{-1})$  is the constant related to the free energy of adsorption.

The correlation coefficients (R2) values for Langmuir model (0.990 for Hg (II) and 0.987 for Mn (II)) were greater than the coefficients for Freundlich model (0.938 for Hg (II) and 0.919 for Mn (II)) and thus the correlation coefficients of Langmuir isotherm were closer to 1 as compared to the Freundlich isotherm. The regression constants are tabulated in Table 2. The high value of correlation coefficient indicated a good agreement between the parameters. The same data is also fitted by the Freundlich equation. The value of correlation coefficients showed that the data fit the Langmuir equation.

#### 3.8. Comparison with other adsorbents

The value of  $q_e$  and adsorption percentage is important to identify which sorbent has the highest adsorption capacity and is useful in scale-up considerations. Table 3 shows the comparison of adsorbent capacity and adsorption percentage of various adsorbents for Hg (II) and Mn (II). When compared with other adsorbents, the surfactant modified mesoporous carbon has higher adsorption percentage in most cases except for MCM-41-NH-L. Higher initial concentrations generally result in higher adsorption capacity (but not adsorption percentage) and it is necessary to consider the adsorption percenage, initial concentrations and adsorption capacity for any comparison. The initial concentrations in this work were less than that reported earlier (Rajic et al., 2009; Chang et al., 2009; Puanngam and Unob, 2008; Yang et al., 2008).

#### 4. Conclusions

In this work, two surfactants were coated on the surface of mesoporous carbon. The structural order and textural properties of the modified and unmodified mesoporous carbons was studied employing XRD and nitrogen adsorption analyses. The modified mesoporous carbons prepared in this work are suitable for the adsorption of mercury and manganese ions from aqueous solutions and initial concentration and pH are determinant factors for the removal of these adsorbates. Sorption of Hg (II) and Mn (II) was low at low pH values and increased with pH. BET surface area, porosity and porous area measurements showed that modification with surfactants can significantly enhance the adsorption capacity of the mesoporous carbons. This can be recommended as an efficient method for the removal of toxic hazardous materials and recovery of precious metals from industrial effluents and processes. It was further shown that the Langmuir isotherm best describes the obtained experimental data suggesting a monolayer mode of adsorption.

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