S.E. MORADI[1]
M.J. BANIAMERIAN[2]

[1]Young Researchers Club, Islamic Azad University-Sari Branch, Iran
[2]Young Researchers Club, Islamic Azad University-Songhor Branch, Iran

THE EFFECT OF MESOPOROUS CARBON MODIFICATION BY NITROGEN ON ITS ENRICHMENT EFFICIENCY OF CHROMATE ION: COMPARISON BETWEEN N-DOPED MESOPOROUS CARBON AND AMINO GRAFTED MESOPOROUS CARBON

In the present work, well ordered, N-doped mesoporous carbon (MCN) sorbent with uniform mesoporous wall, high surface area and pore volume has been fabricated using the simple polymerization reaction between ethylene diamine and carbon tetrachloride in mesoporous silica media. The structural order and textural properties of nanostructured materials were studied by XRD, elemental analysis, and nitrogen adsorption-desorption experiment. Adsorption of chromate over various porous adsorbents such as mesoporous carbon (MC), N-doped mesoporous carbon (MCN), and amino modified mesoporous carbon (AMC) was studied from solutions with different concentration, temperature and pH in polar (water) solvent. The adsorption isotherms of chromate were in agreement with Langmuir model, moreover, the uptake capacity of chromate over MCN was much higher than amino modified mesoporous carbon (AMC) and pristine mesoporous carbon adsorbent.

Keywords: chromate; N-doped mesoporous carbon; adsorption; amino modification.

The presence of chromate (Cr(VI)) and other chrome anions in various sources of water are prominent issues since the toxicity of these species can result in death if these species are taken over either a long period or present in high concentrations. The chemical form of chromates determines their potential toxicity as Cr(VI) is believed to be more hazardous than Cr(III) species [1]. The carcinogenic and toxicity of Cr(VI) is based on its oxidation state where the chromate anion resembles the form of sulfate and phosphate [2]. Hence, the regulation for the limitation of the Cr (VI) concentration in water should be highlighted and emphasized in every country due to the toxicity, reactivity and probable carcinogens of these species. Acceptable limits for chromium in water differ in almost every country. As a guideline, World Health Organization (WHO) recommended a maximum level of 0.050 mg L^{-1} for Cr(VI) in drinking water [3] and the National Institute for Occupational Safety and Health (NIOSH) proposed that the levels of chromium should be reduced to 10^{-3} mg L^{-1} [4].

A number of treatment methods for the removal of metal ions from aqueous solutions have been reported, mainly ion exchange, electrochemical reduction, evaporation, solvent extraction, reverse osmosis, chemical precipitation, membrane filtration and adsorption [5]. Most of these methods involve high capital cost and are not suitable for small-scale industries. The adsorption processes are generally known to be one of the most effective techniques for removal of environmentally hazardous metals. As it is easy to remove the adsorbent from aqueous media after treatment, adsorption technique is generally considered a promising method and has been studied for chromate removal as well. Adsorbents with strong affinity and high loading capacity for targeted metal ions have been developed by modifications of the surface of various substrates, such as polymers and clays with metal complexion groups [6,7]. The removal of

Correspondening author: S.E. Moradi, Young Researchers Club, Islamic Azad University-Sari Branch, Iran.
E-mail: er_moradi@hotmail.com

toxic pollutants from water is a problem, particularly when they are present in low concentrations. Several studies have focused on the fate and transport of these pollutants and the application of remedial technologies to manage them [6-10]. The most common adsorbent material are carbon-based adsorbents, which have huge specific surface areas, plentiful micro and macro pores, and a high adsorption capacities. These adsorbents are economically favorable because they can be made from various low-cost materials that have high carbonaceous content including wood, coal, petroleum coke, sawdust and coconut shell [8].

Recently, Ryoo *et al.* have prepared ordered mesoporous carbons from mesoporous silica templates such as MCM-48, SBA-1 and SBA-15 using sucrose as the carbon source [11-14]. Very recently, Vinu *et al.* have reported the synthesis of mesoporous CN materials based on pyridine- and benzene-ring building blocks by using mesoporous silica as a hard template and ethylenediamine (EDA) and carbon tetrachloride (CTC) as precursors [15].

Adsorption plays an important role in these processes. Therefore, the interactions of such compounds with the mesoporous carbon surface must be studied in detail. The mesoporous carbon materials adsorption capacity depends on quite different factors. Obviously, it depends on the mesoporous carbon's characteristics: texture (surface area, pore size distributions), surface chemistry (surface functional groups) [16,17]. It also depends on adsorptive characteristics: molecular weight, polarity, pK_a, molecular size, and functional groups. The influence of the texture and surface chemistry of carbonaceous sorbent in the adsorption of metallic compounds has been studied for years, and many references on this topic can be found in the literature. The adsorption of chromate ion from aqueous solutions on nanoporous carbons has been recently reviewed [18,19], and it was found that the adsorption capacity is significantly affected by the carbonaceous adsorbent surface chemistry.

Different studies have been done on interaction between polar containing surface groups on carbon surface and the adsorption of different compounds in aqueous solution. There are two types of interactions between the adsorbate and the carbonaceous adsorbent: electrostatic and dispersive [17-19]. The former appears when the adsorptive is dissociated under the experimental conditions used; for the latter three the mechanisms proposed are: π-π dispersion interaction mechanism, the hydrogen bonding formation mechanism, and the electron donor-acceptor complex mechanism. The electron donor-acceptor complex me-

chanism is the most widely accepted [17-19]. The surface chemistry and solution pH are the most important factors controlling the adsorption process [17]. Most of the metallic pollutants are found in water solution in the ionic state for a broad range of pH values, so electrostatic interaction between them and charged functional groups on the carbon surface could be significant [17].

In this work, the influence of the texture and surface chemistry of mesoporous carbon adsorbent were systematically studied in the adsorption of chromate. For this purpose, N-doped mesoporous carbon, amino modified mesoporous carbon and unmodified mesoporous carbon with quite different surface properties were selected in order to analyze the influence of the textural parameters. Interestingly, it was found that the adsorption capability of MCN for chromate is much higher compared to that of other adsorbents. Langmuir and Freundlich adsorption isotherms were studied to explain the sorption mechanism.

EXPERIMENTAL

Materials

The reactants used in this study were tetraethyl orthosilicate (TEOS) as a silica source; cetyltrimethylammonium bromide (CTAB) as a surfactant; sodium hydroxide (NaOH), sodium fluoride (NaF), and deionized water for synthesis of mesoporous silica (MCM-48); sucrose as a carbon source; sulfuric acid as a catalyst for synthesis of mesoporous carbon; EDA (ethylene diamine) and CTC (carbon tetrachloride) for synthesis of N-doped mesoporous carbon (MCN); acetic anhydride and concentrated sulfuric acid for amino modification of mesoporous carbon and chromate. All chemicals were analytical grade and were purchased from Merck.

Experimental procedure

Synthesis of mesoporous silica (MCM-48)

MCM-48 was prepared according to the synthesis procedure described by Shao [20]. In a representative synthesis, the MCM-48 molecular sieves was prepared as follows: 10 mL of tetraethyl orthosilicate (TEOS) was mixed with 50 mL of deionized water, and the mixture was vigorously stirred for 40 min at 308 K, then 0.9 g of NaOH was added into mixture, and at the same time, 0.19 g of NaF was added into the mixture. After the NaF was added completely, the required content (5 mL) of tetraethyl orthosilicate (TEOS), respectively, were added. After another 60 min of vigorously stirring, 10.61 g of cetyltrimethylammonium bromide (CTAB) was added to

the mixture, and stirring continued for 60 min. The mixture was heated for 24 h at 393 K in an autoclave under static conditions, and the resulting product was filtered, washed with distilled water, and dried at 373 K. The as-synthesized samples were then calcined in air for 4 h at 823 K, increasing the temperature to 823 K at 1 °C/min heating rate.

Synthesis of mesoporous carbon (MC)

MC was prepared according to the synthesis procedure described by Ryoo [14]. In a representative synthesis, the MC molecular sieve was prepared as follows: 1.25 g sucrose and 0.14 g H_2SO_4 in 5.0 g H_2O was dissolved, and this solution were added to 1 g MCM-48. The sucrose solution corresponded approximately to the maximum amount of sucrose and sulfuric acid that could be contained in the pores of 1 g MCM-48. The resultant mixture was dried in an oven at 373 K, and subsequently, the oven temperature was increased to 433 K. After 6 h at 433 K, the MCM-48 silica containing the partially carbonizing organic masses was added with an aqueous solution consisting of 0.75 g sucrose, 0.08 g H_2SO_4 and 5.0 g H_2O. The resultant mixture was dried again at 373 K, and subsequently the oven temperature was increased to 433 K. The color of the sample turned very dark brown or nearly black. This powder sample was heated to 1173 K under vacuum using a fused quartz reactor equipped with a fritted disk. The carbon±silica composite thus obtained was washed with 1 M NaOH solution of 50% ethanol-50% H_2O twice at 363 K, in order to dissolve the silica template completely. The carbon samples obtained after the silica removal were filtered, washed with ethanol and dried at 393 K.

Surface modification of mesoporous carbon

AMC was prepared using MC, according to Abe et al. [21]. Briefly, nitration was allowed to proceed in a 1000 mL three-neck flask containing MC, acetic anhydride, and concentrated sulfuric acid with dropwise addition of fuming nitric acid in 5 h while keeping the temperature below 278 K. The reaction was completed after 19 h of stirring at room temperature. Modified MC thus obtained was thoroughly washed with deionized water until the electroconductivity of filtrate attained a value nearly the same as that of the water and vacuum-dried for 24 h at 383 K. Reduction of the nitrated mesoporous carbon was permitted to proceed in a 1000 mL flask containing deionized water, 28% aqueous ammonia, sodium hydrosulfite, and the carbon with stirring for 24 h in nitrogen atmosphere at room temperature. The aminated mesoporous carbon thus obtained was vacuum-dried at 383 K after being washed with deionized water until the electroconduc-

tivity of filtrate became nearly the same as that of the water. This carbon sample is hereafter abbreviated to AMC.

Synthesis of N-doped mesoporous carbon (MCN)

N-doped mesoporous carbon materials were prepared by using mesoporous silica MCM-48 as template. In a typical synthesis, 0.5 g of calcined MCM-48 was added to a mixture of EDA (1.35 g) and CTC (3 g). The resultant mixture was refluxed and stirred at 363 K for 6 h. Then, the obtained dark brown colored solid mixture was placed in a drying oven for 12 h, and ground into fine powder. The template-carbon nitride polymer composites were then heat treated in a nitrogen flow of 50 mL per minute at 873 K with the heating rate of 3.0 °C min^{-1} and kept under these conditions for 5 h to carbonize the polymer. The N-doped mesoporous carbon was recovered after dissolution of the silica framework in 5 mass% hydrofluoric acid, by filtration, washed several times with ethanol and dried at 373 K.

Characterization

The X-ray powder diffraction patterns were recorded on a Philips 1830 diffractometer using CuKα radiation. The diffractograms were recorded in the 2θ range of 0.8-10 with a 2θ step size of 0.01θ and a step time of 1 s.

Adsorption-desorption isotherm of the as-synthesized sample was measured at 77 K on a Micromeritics model ASAP 2010 sorptometer to determine an average pore diameter. Pore-size distribution was calculated by the Barrett-Joyner-Halenda (BJH) method while Brunauer-Emmett-Teller (BET) measured surface area of the sample.

Adsorption studies

A stock solution of 200 mg L^{-1} for Cr(VI) was prepared by dissolving an appropriate amount of the Cr(VI) in ultra-pure water (18 MΩ cm) derived from a Milli-Q plus 185 water purifier. Batch adsorption isotherms were performed by shaking 500 mL amber Winchester bottles containing the required concentration of the Cr(VI) in a Gallenkamp incubator shaker. The shaker was set at temperatures of 298, 308 and 318 K and a speed of 150 rpm. Initial solution concentration of 10-100 mg L^{-1} was prepared by pipetting out the required amounts of the Cr(VI) from the stock solution. The volume of solution in each bottle was maintained at 500 mL and the solutions were adjusted to pH 5. About 0.01 mg of each adsorbent was weighed accurately on aluminum foils using a Sartorious (model BP 201D) analytical balance. The adsorbents were transferred carefully into

the bottles using 50 mL solutions from the bottles. The bottles were shaken vigorously before shaking for different time in the incubator shaker (New Brunswick Scientific C25 model).

The amount of Cr(VI) adsorbed was calculated by subtracting the amount found in the supernatant liquid after adsorption from the amount of Cr(VI) present before addition of the adsorbent by UV-Vis spectrophotometer (UV mini 1240 Shimadzu). Absorbance was measured at wavelength (λ_{max}) 372 nm [22]. Centrifugation prior to the analysis was used to avoid potential interference from suspended scattering particles in the UV-Vis analysis.

The adsorption capacities were calculated based on the differences of the concentrations of solutes before and after the experiment according to Equation (1) [23]:

$$q_e = \frac{(c_0 - c_e)V}{W} \qquad (1)$$

where q_e is the concentration of the adsorbed solute (mmol/g), c_0 and c_e are the initial and final (equilibrium) concentrations of the solute in solution (mmol/L), V (mL) is the volume of the solution and W (g) is the mass of the adsorbent.

Adsorption kinetics of Cr(VI)

For the measurement of the time resolved uptake of Cr(VI) onto adsorbents, 15 mL of distilled water was mixed with 60 mg of adsorbent in a 500 mL flask for about 10 min. 285 mL of Cr(VI) solution was quickly introduced into the flask (keeping the initial

concentrations of the resulting solutions at 100 mg/lit) and stirred continuously at 298 K. Samplings were done by fast filtration at different time intervals. The concentration of residual Cr(VI) in the solution was determined and the adsorption amount q_t was calculated according to Eq. (2) [24]:

$$q_t = \frac{(c_0 - c_t)V}{W} \qquad (2)$$

where q_t is the adsorption amount at time t, c_0 is the initial concentration of Cr(VI) solution, c_t is the concentration of Cr(VI) solution at time t and V is the volume of Cr(VI) solution and W is the mass of MC, AMC and MCN.

RESULT AND DISCUSSION

Characterization

Adsorption-desorption analysis

Besides PXRD, nitrogen physisorption is the method of choice to gain knowledge about mesoporous materials. This method gives information on the specific surface area and the pore diameter. Calculating pore diameters of mesoporous materials using the BJH method is common [25]. Former studies show that the application of the BJH theory gives appropriate qualitative results, which allow a direct comparison of relative changes between different mesoporous materials [26-29].

Figure 1 shows nitrogen adsorption and desorption isotherms measured at 77 K by using a Micro-
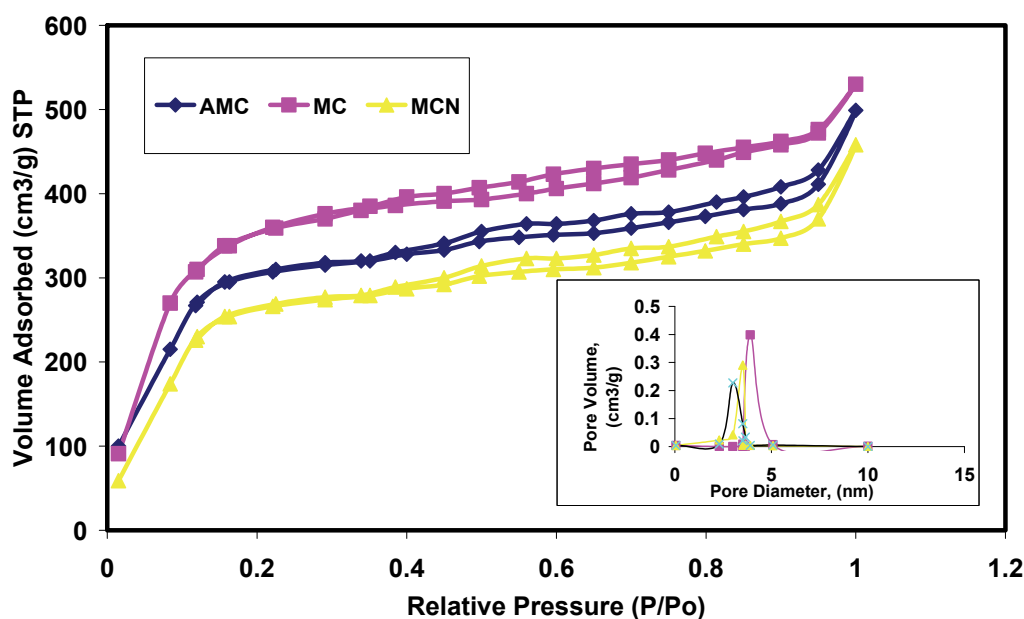

Figure 1. Adsorption-desorption isotherms of nitrogen at 77 K on a) MC, b) AMC and c) MCN. The insert shows the BJH pore size distribution calculated from the desorption branch of the isotherm.

meritics ASAP 2010 automatic analyzer. BET surface areas and the pore size determined by BJH (Barrett, Joyner and Halenda) method for the synthesized mesoporous sorbents (MC, AMC and MCN) were determined by the adsorption branches of the isotherms. All mesoporous materials yield a type IV isotherm. The isotherm of MC is reversible and in good agreement with that previously reported.

Table 1 summarizes the important physical properties of mesoporous sorbents. The surface areas of MC, AMC and MCN samples were 1432, 1321 and 1280 m^2/g, and their average pore size were 4.6, 3.5 and 4.1 nm, respectively. This result mainly depends on the pore size and shape for all nanostructured carbon materials.

Table 1. Textural parameters of the MC, AMC and MCN employed in this study

Adsorbent	d Spacing, nm	A_{BET} / m^2 g^{-1}	V_p / cm^3 g^{-1}
MC	4.6	1432	0.74
AMC	3.5	1321	0.69
MCN	4.1	1280	0.72

XRD Analysis

The XRD patterns of MC showed the two characteristic (211) and (220) reflections in the 2θ range from 0.8 to 10°, indicating a well-ordered cubic pore (Figure 2). Like MC, the XRD patterns of AMC and MCN showed three diffraction peaks that can be indexed to (110), (210), and (220) in the 2θ range from 0.8 to 10°, representing well-ordered cubic I4132 pores. The observation data from the original samples of all nanostructured carbons are in good agreement with that previously reported [12].

Elemental analysis

Table 2 shows the results of elemental analysis performed to check if nitrogen-containing groups have really been introduced to the mesoporous carbon adsorbents. Since 2.1 and 17.5% of nitrogen was detected for AMC and MCN though no nitrogen was detected for MC, the results in the table demonstrate the presence of nitrogen-containing functional groups in both modified mesoporous carbon sorbents.

Adsorption studies

Effect of agitation speed

The effect of agitation speed on removal efficiency of chromate on mesoporous carbon sorbents (MC, AMC and MCN) was studied by varying the speed of agitation from 0 (without shaking) to 250 rpm, while keeping the analyte concentration, contact time, pH, temperature and dose of the adsorbent as constant. As it is demonstrated in Figure 3, the chromate removal efficient generally increased with increasing agitation speed from 0 to 250 rpm and the adsorption capacity of all adsorbents remained constant for agitation rates greater than 150 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 150-250 rpm is sufficient to assure that the maximum available sites of adsorbent existing in the pores of adsorbents are made readily available for chromate uptakes. For convenience, agitation speed of 150 rpm was selected as the optimum speed for all the adsorption experiments.
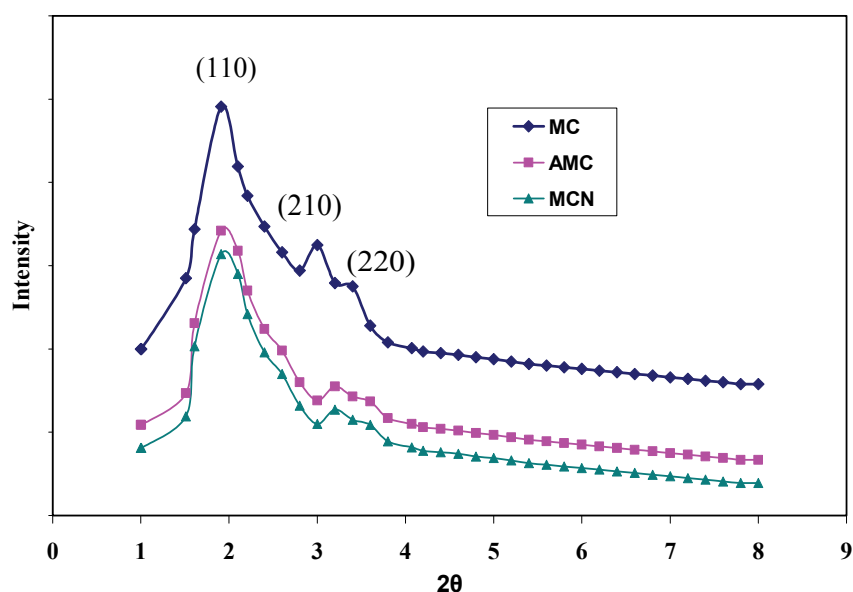

Figure 2. XRD Pattern of a) MC, b) AMC and c) MCN.

Table 2. Elemental analyses (%) of mesoporous carbons

Sample	C	H	N
MC	93.5	0.49	0
AMC	89.8	1.48	2.1
MCN	75.8	3.2	17.5

Effect of contact time and concentration

In order to establish equilibration time for maximum uptake and to know the kinetics of adsorption process, the adsorption of chromate on carbonaceous adsorbent was studied as a function of contact time and results are shown in Figure 4. It is seen that the rate of uptake of the chromate is rapid in the beginning and 60% adsorption is completed within an hour. Figure 4 also indicates that the time required for equilibrium adsorption is 5 h. Thus, for all equilibrium adsorption studies, the equilibration period was kept at 7 h. The effect of concentration on the equilibration time was also investigated on mesoporous carbon sorbent as a function of initial chromate concentration and the results are shown in Figure 5. It was found that time of equilibrium as well as time required to achieve a definite fraction of equilibrium adsorption is independent of initial concentration. These results indicate that the adsorption process is first order.
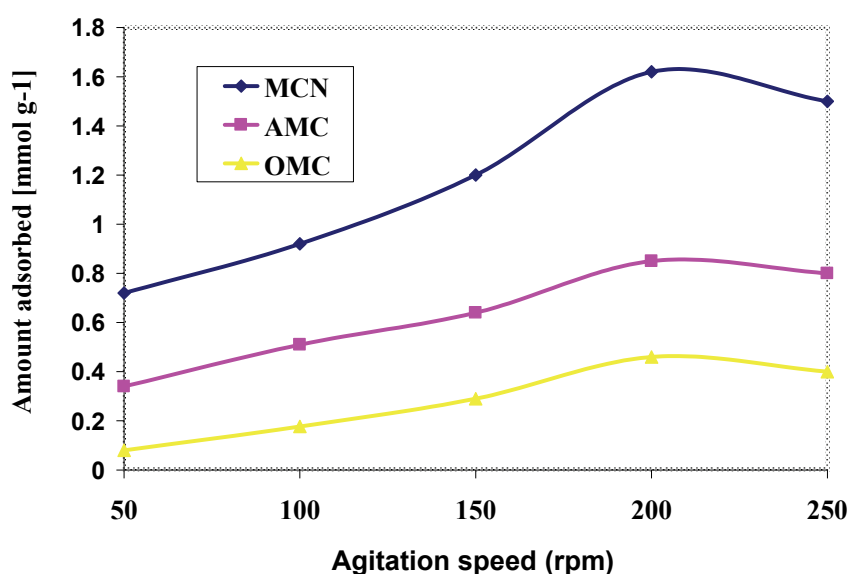

Figure 3. Effect of agitation speed on the adsorption percent of different mesoporous carbon adsorbents
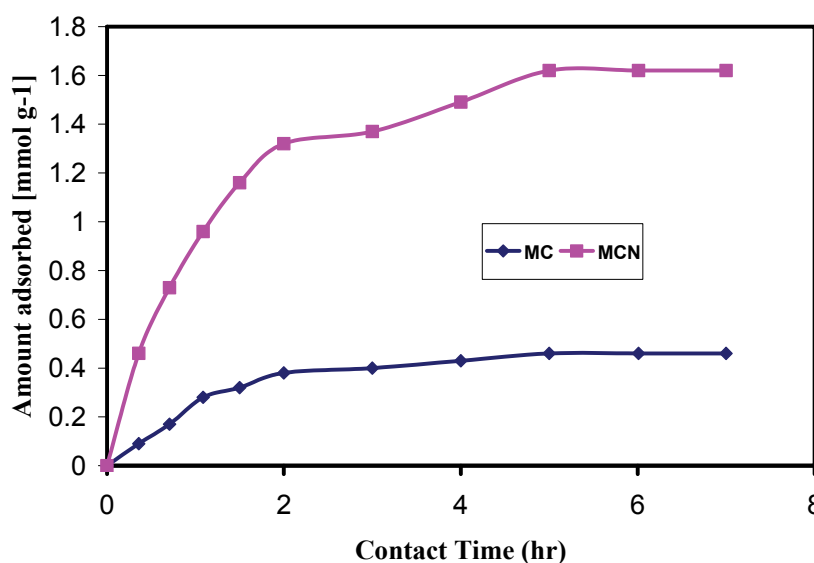(adsorbent dosage, 0.2 gr/L, [Cr(VI)] = 100 mg/L, contact time, 5 h, T = 298 K and pH 7).

Figure 4. Effect of contact time on removal of chromate ([Cr(VI)] = 100 mg/L, agitation speed, 150 (rpm),
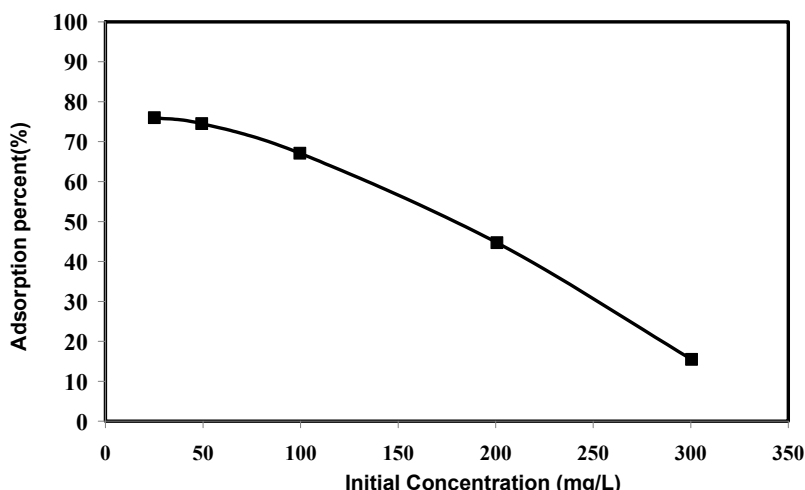adsorbent dosage, 0.2 g/L and room temperature, 298 K).

Figure 5. Effect of initial concentration on removal of Cr(VI) (contact time, 5 h, agitation speed, 150 rpm, amount of MC, 0.2 g/L, T = 298 K and pH 7).

Effect of temperature

The effect of temperature of adsorption was studied in the range 298-318 K. The initial concentration of Cr(VI) is 50 mg/L, respectively. The results are shown in Figure 6. The conclusion could be attained from Figure 6 that the adsorption capacity of Cr(VI) by MCN is enhanced with the increase of temperature. The amount of adsorption also increases with contact time increases. This indicate that the temperature is higher the maximum amount of Cr(VI) reaches 2.14 mmol/g. On the other hand, when the temperature is 298 K the maximum amount of Cr(VI) reaches 1.62 mmol/g. In the case of physical adsorption, the amount adsorbed increases as the temperature decreases

[30], but the amount of Cr(VI) onto MCN increases as the temperature increased. This phenomena may be due to the increase of the rate of intraparticle of Cr(VI) into the pores of the adsorbent at higher temperatures which indicates that the diffusion reactions play an important role in the process of adsorption [31,32].

pH Effect

The removal of Cr(VI) from water by an adsorbent is highly dependent on the pH of the solution, which subsequently affects the surface charge of the adsorbent, the degree of ionization and the speciation of the adsorbate species [33]. In water as well, Cr(VI) anion is not a simple monovalent anion but rather a series of chromate anions depending upon the pH
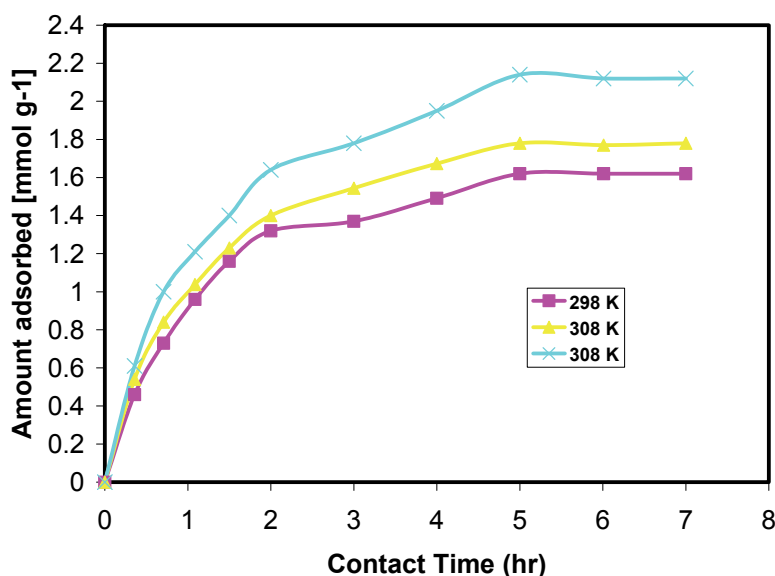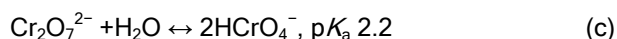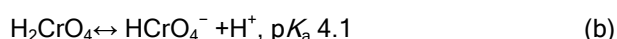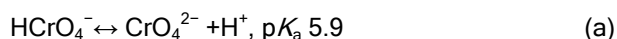

Figure 6. Effect of temperature on adsorption of Cr(VI) by MCN ([Cr(VI)] = 100 mg/L, agitation speed, 150 rpm, amount of MCN, 0.2 gr/L, T = 298 K and pH 7).

and the concentration of the solution. Therefore, it was important to study the effect of pH on the removal of Cr(VI) onto carbonaceous adsorbents. Figure 7 shows the effect of pH, ranging from 2 to 10 on the removal of Cr(VI) by MCN, AMC and MC. The removal capacities of Cr(VI) by all sorbents were observed to be the highest when Cr(VI) solution having pH 5 while the lowest sorption capacity at pH 10. The Cr(VI) species may be represented in various forms such as H_2CrO_4, $HCrO_4^-$, CrO_4^{2-} and $Cr_2O_7^{2-}$ in the solution phase as a function of pH. Cr(VI) speciation is affected by solution pH through the following equilibrium [34]:

$$HCrO_4^- \leftrightarrow CrO_4^{2-} +H^+, \; pK_a \; 5.9 \qquad (a)$$

$$H_2CrO_4 \leftrightarrow HCrO_4^- +H^+, \; pK_a \; 4.1 \qquad (b)$$

$$Cr_2O_7^{2-} +H_2O \leftrightarrow 2HCrO_4^-, \; pK_a \; 2.2 \qquad (c)$$

Above pH 6, the dominant species is the yellow chromate anion, CrO_4^{2-}, between pH 2 and 6, $HCrO_4^-$ and dichromate ion, $Cr_2O_7^{2-}$ is in equilibrium [35]. From Eq. (a), the major species are $HCrO_4^-$ at pH 5 and CrO_4^{2-} at pH 7. Because of the distribution of Cr(VI) in water which is in the form of anion, it is clearly indicated that the MCN and AMC are suitable to adsorb Cr(VI) species in water at suitable pH. The adsorption efficiency of Cr(VI) was highest at pH 4 for each of the carbonaceous adsorbents while the adsorption decreased when the pH increased. This is due to the dominant species of Cr(VI) which exist in water and the exchange capacity of the carbonaceous adsorbent for one species. As described above, at lower pH, the Cr(VI) species are mostly in the univalent form ($HCrO_4^-$) and thus require one exchange site for one molecule of Cr(VI) species at that pH. In contrast, at high pH, the divalent form of Cr(VI) species ($Cr_2O_7^{2-}$, CrO_4^{2-}) are mostly present and necessitate two exchange sites from adsorbent for the adsorption to occur. This resulted in higher removal capacity of Cr(VI) species by MCN, AMC and MC at lower pH than that at higher pH. In addition, the lower affinity of Cr(VI) sorption at pH 10 may also be influenced by the strong competition from OH^- with chromate anion for the sorption sites since more OH^- are present at high pH. In addition, at pH values greater than 6, the presence of OH^- forms the hydroxyl complexes of chromium.

Adsorption isotherms

In order to evaluate the efficacy of the prepared adsorbents, the equilibrium adsorption of the chromate was studied as a function of equilibrium concentration. The adsorption isotherms of chromate on adsorbents are shown in Figure 8. It is seen that the order of adsorption in terms of amount adsorbed (mmol/g) on different adsorbents is: MCN >AMC>MC.

This appears due to nitrogen containing carbonaceous adsorbent, which has much better interaction with chromate as compared to pristine mesoporous carbon adsorbent tends to adsorb chromate in amounts appreciably larger. The performance of amino modified mesoporous carbon in the adsorption of chromate is lower than MCN because of the low content of nitrogen in carbon skeleton and weak interaction of amino group in AMC with chromate ion. In order to indicate the sorption behavior and to estimate of adsorption capacity, adsorption isotherms have been studied. The adsorption process of chromate was tested with Langmuir and Freundlich isotherm models. Two commonly used empirical adsorption
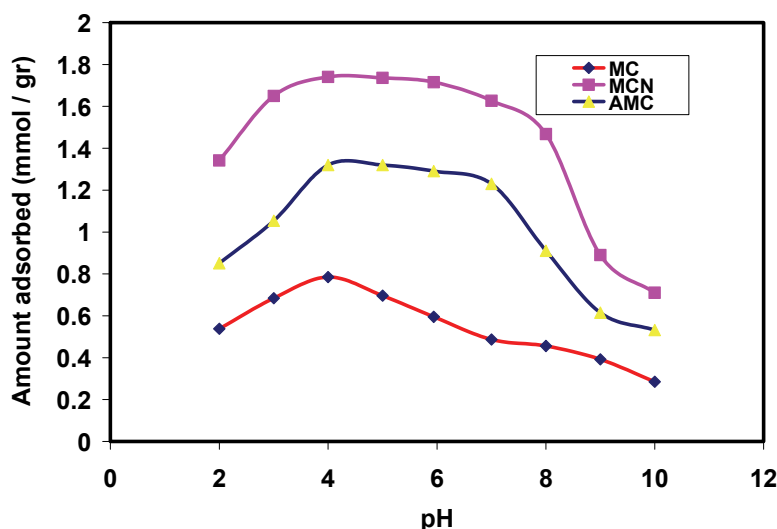

Figure 7. Effect of pH on chromate ion removal over MCN, AMC and MC ([Cr(VI)] = 100 mg/L, adsorbent dose, 0.2 g/L, agitation speed, 150 rpm and temperature 298 K).
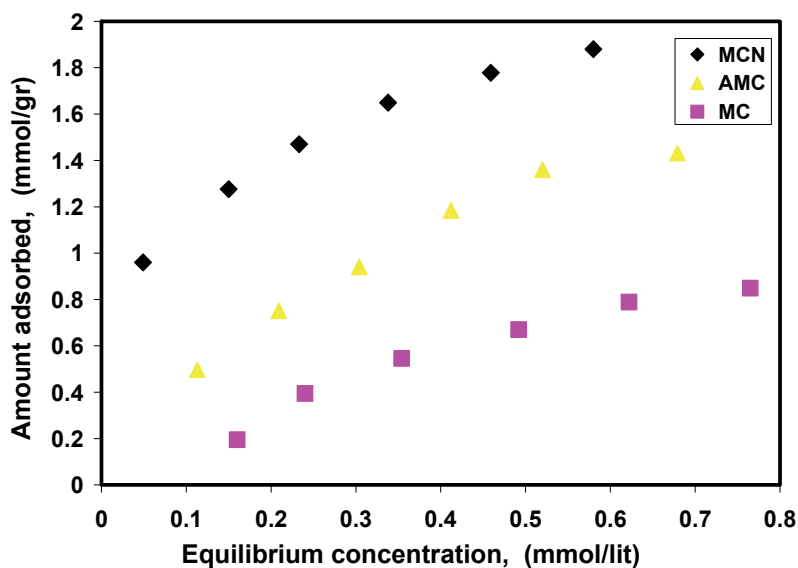
Figure 8. Adsorption isotherm for chromate ion removal on adsorbents (contact time, 7 h, agitation speed, 150 rpm, amount of MC, 0.2 g/L, T = 298 K and pH 5).

models, Freundlich and Langmuir, which correspond to heterogeneous and homogeneous adsorbent surfaces, respectively, were employed in this study. The Freundlich model is given by Equation (3):

$$\ln q_e = \ln K_f + \frac{1}{n}\ln c_e \qquad (3)$$

where K_f and n are the Freundlich constants related to adsorption capacity and intensity, respectively. In the second model, the Langmuir equation assumes maximum adsorption occurs when the surface is covered by the adsorbate, because the number of identical sites on the surface is finite. Equation (4) (Langmuir equation) is given as follows:

$$\frac{c_e}{q_e} = \frac{1}{q_m b} + \frac{1}{q_m}c_e \qquad (4)$$

where q_e (mmol g^{-1}) is the amount adsorbed at equilibrium concentration c_e (mmol L^{-1}), q_m (mg g^{-1}) is the Langmuir constant representing maximum monolayer capacity and b is the Langmuir constant related to energy of adsorption.

The isotherm data has linearized using the Langmuir equation. The regression constants are tabulated in Table 3. The high value of correlation coefficient ($R^2 = 0.99$) indicated a good agreement between the parameters. The constant q_m, which is a measure of the adsorption capacity to form a monolayer, and the constant b, which denotes adsorption energy are fitted by the Freundlich equation. The regression constants are listed in Table 3. The value of correlation coefficients showed that the data conform well to the Langmuir equation.

Table 3. Isotherm constants for adsorption of chromate ion on MCN

Langmuir constants			Freundlich constants		
q_m / mmol g^{-1}	B / L mmol^{-1}	R^2	K_F / mmol g^{-1}	n / L mmol^{-1}	R^2
3.763	41.159	0.9989	5.2328	0.725	0.933

CONCLUSION

In this work, N-doped mesoporous carbon was utilized that has been prepared by cubic mesoporous silica MCM-48. The structural order and textural properties of all the materials have also been studied by XRD, elemental analysis and nitrogen adsorption-desorption analysis. Adsorption of chromate over various porous adsorbents such as MC, AMC and MCN has been studied. It has been found that the amount of chromate adsorption on MCN is higher as compared to the other novel nanoporous carbon adsorbent. The adsorption behavior of chromate on the MCN from aqueous solution has been investigated. All adsorption isotherms were fitted well by Langmuir model.

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S. E. MORADI[1]
M.J. BANIAMERIAN[2]

[1]Young Researchers Club, Islamic Azad University-Sari Branch, Iran
[2]Young Researchers Club, Islamic Azad University-Songhor Branch, Iran

NAUČNI RAD

UTICAJ MODIFIKACIJE MEZOPOROZNOG UGLJENIKA AZOTOM NA EFIKASNOST ADSORPCIJE HROMAT JONA: POREĐENJE N-DOPIRANOG I AMINO MODIFIKOVANOG MEZOPOROZNOG UGLJENIKA

U ovom radu je sintetisan N-dopiran mezoporozni ugljenik (MCN), sorbent sa jedinstvenim mezoporoznim zidom, razvijene površine i zapremine pora, koristeći jednostavne polimerizacione reakcije između etilen diamina i ugljentetrahlorida u mezoporoznom medijumu silicijuma. Ispitivanje strukture i svojstva teksture nanostrukturnih materijala izvršeno je XRD, elementarnom analizom i adsorpcijom/desorpcijom azota. Ispitan je uticaj promene koncentracije, temperature i pH na adsorpciju hromata na raznim poroznim adsorbentima, kao što su ugljenik-mezoporozni (MC), N-dopirani mezoporozni ugljenik (MCN) i amino-modifikovani mezoporozni ugljenik (AMC) u polarnim (voda) rastvarā čima. Adsorpcione izoterme hromata su u saglasnosti sa Langmuirovim modelom. Nađeno je da je kapacitet adsorpcije hromata na MCN mnogo veći nego na amino-modifikō vanom mezoporoznom ugljeniku (AMC) i netretiranom mezoporoznom adsorbensu ugljenika.

Ključne reči: hromat; N dopiran mezoporozni ugljenik; adsorpcija; amino modifikacija.

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