



Application of zeolitic material synthesized from thermally treated sediment to the removal of trivalent chromium from wastewater

Qingyu Guan, Deyi Wu*, Yan Lin, Xuechu Chen, Xinze Wang, Chunjie Li, Shengbing He, Hainan Kong

School of Environmental Science and Engineering, Shanghai Jiao Tong University, No. 800, Dongchuan Rd., Minhang District, Shanghai 200240, China

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ABSTRACT

Zeolitic materials were synthesized from thermally treated sediment by alkali treatment using different NaOH/sediment ratios. Characterization of the materials was done by XRD, FTIR, cation exchange capacity and specific surface area. Use of high NaOH/sediment ratio favored the formation of zeolite. The potential value of the zeolitic materials for the retention of trivalent chromium from water was examined. The maximum of Cr(III) sorption by the zeolitic materials, determined by a repeated batch equilibration method, ranged from 38.9 to 75.8 mg/g which was much greater than that of the thermally treated sediment (6.3 mg/g). No release of sorbed Cr(III) by 1.0 M MgCl₂ at pH 7 was observed but Cr(III) desorption by ionic electrolyte increased with decreasing pH. The zeolitic materials could completely remove Cr(III) from wastewater even in the presence of Na⁺ and Ca²⁺ with high concentrations with a dose above 2.5 g/L. The pH-dependent desorption behavior and the high selectivity of zeolitic material for Cr(III) were explained by sorption at surface hydroxyl sites and formation of surface precipitates.

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1. Introduction

Most pollutants entering into water bodies accumulate eventually in sediments, which are not only the habitats for benthic organisms but may again become a source of water pollution. Therefore, treatment of heavily contaminated sediment from river, harbor, estuary or other sites is obligatory. Thermal treatment in a rotary kiln is among the most promising and economic ex situ sediment remediation alternatives [1–5].

To conduct ex situ treatment, however, all heavily contaminated sites have to be fully excavated and remediated to obtain clean solids whereas flue gas could be usually treated by incineration (1000–1100 °C) and dedusting. The amount of dredged sediment is usually huge. By taking into account the huge amount of dredged sediment and the scarcity of land especially in city areas where sediment is usually heavily polluted and thus remediation is required, investigation on the productive reuse of heated sediment is very important.

Zeolites are useful crystalline aluminosilicate materials, having infinite, three-dimensional structures. Zeolites have been received increasing attention for removal of contaminants such as heavy metals and radionuclides from wastewater, owing to their large specific surface area (SSA) and cation exchange capacity (CEC). In recent

years, synthesis of zeolite from coal fly ash, a by-product generated every year in great amounts in the world, has been investigated intensively [6–12]. In addition, usefulness of the synthesized zeolite in the application of the removal of heavy metals has been reported [13–21].

It is notable that thermally treated sediment and coal fly ash share similarities because both are derived from inorganic minerals (contained in sediment or coal), thus constituted mainly of silica and alumina, and both experienced heat treatment. Silica and alumina are the elements of the framework of zeolite structure, while heat treatment could result in the formation of amorphous phase of aluminosilicates, which is the most reactive in conversion into other crystalline minerals, such as zeolites. In fact, these are the reasons why coal fly ash could be easily converted to zeolites and why the synthesis of zeolite from coal fly ash has drawn much attention from researchers.

Taking into account the similarity between coal fly ash and heated sediment, the present study was undertaken to investigate the conversion of thermally treated sediment into zeolite and to examine the potential value of the obtained zeolitic material for the removal of trivalent chromium from aqueous solution/wastewater. Trivalent chromium was selected as a representative heavy metal because (1) chromium is one of the regulated toxic heavy metals in the environment and (2) trivalent chromium is one of the main oxidation states of chromium and is extensively used in the leather tanning, paints and pigments, fungicides industries, and in ceramic and glass manufacture.

* Corresponding author. Tel.: +86 21 5474 4540; fax: +86 21 5474 0825.

E-mail addresses: dywu@sjtu.edu.cn, wudeyi333@yahoo.com.cn (D.Y. Wu).

2. Experimental

2.1. Synthesis and characterization of zeolitic materials

A sediment sample was collected from the Suzhou Creek near Wuning Road in the city area of Shanghai, China. After being air-dried, the sample was ground to pass through a 60-mesh sieve and was then heated at 800 °C for 30 min. The thermally treated sediment had the chemical composition of SiO₂ 69.0%, Al₂O₃ 11.8%, Fe₂O₃ 5.1%, CaO 4.3%, MgO 2.3%, K₂O 1.0%, Na₂O 1.0% (the chemical composition for original sediment sample is SiO₂ 72.1%, Al₂O₃ 10.2%, Fe₂O₃ 5.4%, CaO 4.1%, MgO 2.0%, K₂O 1.1%, Na₂O 0.9%). The equipment for elemental analysis is inductively coupled plasma atomic emission spectroscopy (ICP-AES) equipment (IRIS advantage 1000). The detailed method for chemical composition analysis was described in a previous paper [19]. In the first, 20 g of the heated sediment was mixed and ground with different amounts of NaOH to obtain homogeneous mixtures with NaOH/sediment ratios of 0.8, 1.2, 1.6 and 2.0 g/g, respectively, and was then heated in a nickel crucible in a muffle furnace at 550 °C for 60 min. Secondly, the fusion product was dissolved in 200 mL of doubly distilled water in a flask and was boiled with reflux for 12 h with stirring. The temperature of the solution was 95 °C during the reaction process as determined by a thermometer. At the end of the synthesis process, the solid phase was separated by centrifugation, washed with doubly distilled water three times and with ethanol twice and finally dried in an oven at 45 °C. Hereafter, the four produced zeolitic materials were denoted as Z-0.8, Z-1.2, Z-1.6 and Z-2.0, respectively.

The crystalline phase(s) in the materials were identified by powder X-ray diffraction method on a D8 ADVANCE X-ray diffractometer using a Ni filtered Cu K α radiation (40 kV, 40 mA). The FTIR spectra were recorded by a FTIR spectrophotometer (SHIMADZU IRPrestige-21) using a KBr method. The CEC was determined by the ammonium acetate method [22]. The SSA was determined by fitting the amount of N₂ adsorbed at –196 °C for the BET equation after the preliminary heating at 200 °C (equipment model: ASAP2010).

2.2. Cr(III) sorption tests

Repeated batch equilibrations were conducted to measure the maximum immobilization capacity of zeolitic materials and the thermally treated sediment for Cr(III). Forty millilitres of Cr(III) solution with an initial concentration of 200 mg Cr(III)/L and a pH value of 3.36 was put into a pre-weighed centrifuge tube (W1) containing 0.4 g of sample (W2). After being shaken for 4 h, the suspension was centrifuged, the supernatant was poured into another container, and the tube with the residue was weighed again (W3). The volume of the residual solution (V) was calculated by assuming the density of the residual solution as 1 g/mL: $V(\text{mL}) = W3(\text{g}) - W1(\text{g}) - W2(\text{g})$. The obtained supernatant was analyzed for Cr(III) concentration (C) and the amount of Cr(III) that remained in the residual solution (R), as well as the amount of Cr(III) sorbed by the sample (S), were calculated by the equations: $R(\text{mg}) = [V(\text{mL}) \times C(\text{mg/L})] / 1000$ and $S(\text{mg/g}) = [(200 - C)\text{mg/L} \times 0.04\text{L}] / W2\text{g}$. The volume of the residual solution and the amount of the remaining Cr(III) were considered in the calculation of the initial volume and the initial concentration of the subsequent equilibration step. A fresh solution of the same Cr(III) concentration was added and equilibration was repeated until no further uptake by the materials was observed. The amount of retained Cr(III) was thus calculated. The experiments were performed in duplicate, and the mean data are reported.

To test the reversibility of the sorbed Cr(III), the residues were extracted consecutively with 1 mol/L MgCl₂ solution (pH 7.0) for 1 h, with 1 mol/L NaOAc (adjusted to pH 4.8 with acetic acid) for 5 h, and with 1 mol/L NaOAc (adjusted to pH 3.5 with acetic acid)

for 5 h, respectively. After each extraction, separation was done by centrifuging, and the supernatant was analyzed for chromium. Prior to the next extraction step, the residue was washed with 8 mL of distilled water, centrifuged, and the supernatant was combined with the previous extract.

In addition, a Cr(III) containing wastewater was obtained from a tannery factory in Wenzhou, Zhejiang province, China. The concentrations of main cations in the wastewater were measured by Inductively Coupled Plasma Atomic Emission Spectrometry (IRIS advantage 1000). A given amount of the zeolitic materials was mixed with 40 mL of the wastewater to investigate the effect of dosage on Cr(III) removal. After being shaken for 4 h, the pH of the suspensions was measured with a Hach 51910 pH meter and then they were centrifuged.

The Cr(III) concentrations in the supernatants were determined using a Unicop spectrophotometer (model UV-2102PCS). Cr(III) was first converted into the hexavalent form after oxidation with potassium permanganate at elevated temperature and acidic conditions and then the Cr(VI) concentration was determined at 543 nm following the 1,5-dephenyl-carbazide method [23]. The efficiencies of Cr(III) removal were calculated from the differences between the initial and the final Cr concentrations in solution. The results are means of two replicate experiments.

3. Results and discussion

3.1. Formation and characterization of zeolitic material from heated sediment

The XRD patterns of the original and heated sediment and the zeolitic materials are shown in Fig. 1. The original sediment contained illite and kaolinite in addition to α -quartz. However, the dominant mineral in the thermally treated river sediment is α -quartz which is known to be resistant to heat [6–12]. No other crystalline minerals were detected. This indicates that the thermally treated sediment is mainly composed of amorphous

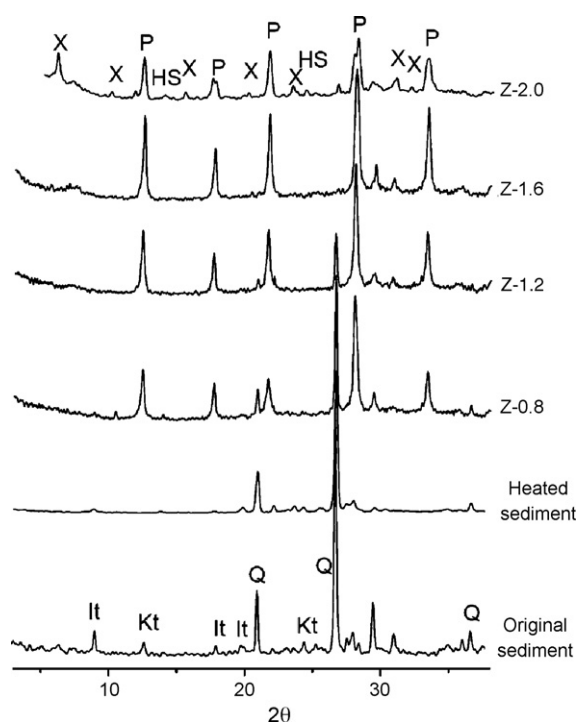


Fig. 1. The XRD patterns of the heated sediment and the zeolitic materials. P, Na-P1 zeolite; HS, hydroxysodalite; X, Na-X zeolite; Q, α -quartz; It, illite; Kt, kaolinite.

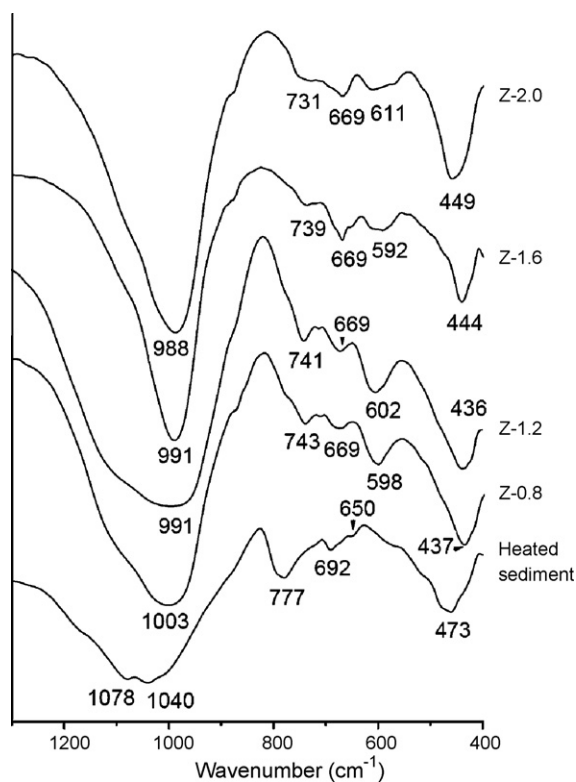


Fig. 2. FTIR spectra of the heated sediment and the zeolitic materials.

phase, analogous to coal fly ash [6–12]. When the heated sediment was melted with NaOH followed by crystallization of the melted product, zeolites were produced. At the same time, the peaks arising from α -quartz were weakened and finally disappeared at the NaOH/sediment ratio ≥ 1.6 . This suggested that quartz was dissolved during the synthesis process, and the dissolution was favored by increasing the NaOH/sediment ratio. The kind of formed zeolite depended on the NaOH/sediment ratio. At the NaOH/sediment ratio ≤ 1.6 , a monophase of Na-P1 zeolite was yielded. The increase in the intensity of Na-P1 peaks with increasing NaOH/sediment ratio intimates the increase in the content of Na-P1 zeolite. But at the NaOH/sediment ratio of 2.0, the intensity of the peaks due to Na-P1 weakened and new zeolites with lower Si/Al ratios (Na-X and hydroxysodalite) appeared instead. This suggests that use of high NaOH/sediment ratio facilitates the formation of zeolites with low Si/Al ratio.

The FTIR spectra of the heated sediment and the zeolitic materials are given in Fig. 2. The vibrations of aluminosilicate framework give rise to absorption bands in the range 1250–400 cm^{-1} [9,10,24,25]. The most important absorption bands on the FTIR spectra are the strong and very broad bands in the range 1180–950 cm^{-1} . These bands are generally assigned to the asymmetric internal T–O stretching vibrations of the TO_4 (where T = Si or Al) tetrahedra. The bands between 475 and 420 cm^{-1} are attributed to the bending vibrations of T–O in the tetrahedra. The 777 cm^{-1} band is assigned to the symmetric stretching vibration mode of O–T–O groups [25]. It can be seen from Fig. 2 that, as the zeolites formed, the bands in the range 1180–950 cm^{-1} for the heated sediment shifted not only to lower wavenumbers but also strengthened in intensity. It appeared that the shift in wavenumber and the increase in the intensity of the band(s) became more pronounced when increasing NaOH/sediment ratio. It has been reported that the length of Al–O bond is longer than that of Si–O and the substitution of tetrahedral Al for Si in aluminosilicate frameworks induces the low wavenumber shift of the stretching vibration T–O band [9,10,25].

Table 1

CEC and SSA values of the heated sediment and the zeolitic materials.

| Sample | CEC (cmol/kg) | Specific surface area (m^2/g) |
|-----------------|---------------|---|
| Heated sediment | 4.2 | 1.4 |
| Z-0.8 | 201.8 | 28.4 |
| Z-1.2 | 279.1 | 36.5 |
| Z-1.6 | 295.3 | 40.0 |
| Z-2.0 | 272.4 | 23.3 |

Since tetrahedral Al is characteristic for zeolite structure, the change of band(s) within range 1180–950 cm^{-1} would suggest that increase in NaOH/sediment ratio caused either the increase in zeolite content (in the case of NaOH/sediment ratio ≤ 1.6) or the formation of zeolites having low Si/Al ratio (in the case of NaOH/sediment ratio = 2.0). This result is clearly in accordance with that of XRD analysis.

With respect to zeolitic materials, the bands at 731–743 cm^{-1} and the band at 669 cm^{-1} could be assigned to the symmetric stretching vibration mode of Al–O for the Si–O–Al framework, while bands at 592–611 cm^{-1} could be ascribed to the parallel 4- or 6-membered doubling rings [24]. The bands due to the bending vibrations of T–O, observed at 436–449 cm^{-1} , are located at lower frequencies than the heated sediment (at 473 cm^{-1}).

The CEC and SSA values of the thermally treated sediment as well as the zeolitic materials are listed in Table 1. The thermally treated sediment had not only a very low CEC value but also a very low SSA value. Formation of zeolite gives rise to a great increase in both CEC and SSA. Up to the NaOH/sediment ratio of 1.6, both the CEC and SSA of zeolitic material increased with the increase of the ratio (Table 1). This is not surprising since the XRD and FTIR results have already shown an increase in zeolite content with increasing the ratio up to 1.6. The CEC and SSA fall slightly at the NaOH/sediment ratio of 2.0 as a result of the formation of small amount of hydroxysodalite whose small pore size (0.23 nm) do not allow the ammonium ion and the N_2 molecule (with diameters of 0.28 and 0.364 nm, used to determine CEC and SSA, respectively) to penetrate. It should be noted, however, that trivalent chromium has a Goldschmidt ion diameter of 0.106 nm and thus may enter the pores of all zeolites obtained.

3.2. Sorption of Cr(III) and the reversibility of sorbed Cr(III)

The experiment was carried out by treating a 200 mg Cr(III)/L solution with the thermally treated sediment and the zeolitic materials using a dose of 10 g/L. Zeolitic materials showed almost complete removal for trivalent chromium (the removal efficiencies > 98%). While the thermally treated sediment showed very limited removal efficiencies of 29.4%. Repeated batch equilibration experiments revealed that the efficiency of Cr(III) removal by the heated sediment declined to be negligible at the second time of equilibration. Whereas zeolitic materials could be used consecutively for 4–8 times to remove trivalent chromium. The higher the NaOH/sediment ratio used to synthesize zeolite, the more the times the zeolitic material could be consecutively used for the removal of trivalent chromium. The maximum immobilization capacity of the heated sediment and the zeolitic materials are presented in Table 2. For comparison purpose, the maximum immobilization capacity of other sorbents reported in literatures was also summarized in Table 2. It can be seen that Cr(III) sorption capacity of the zeolitic materials is among the highest, indicating that they are promising materials for Cr(III) removal from wastewater. Removal capacity of zeolitic material for trivalent chromium increased with increasing NaOH/sediment ratio, which was a principal parameter for zeolite synthesis.

The reversibility of Cr(III) sorption is important not only for the evaluation of sorbent but also for the understanding of sorption

Table 2
Comparison of Cr(III) immobilization maxima of tested materials with some literature values.

| Type | Sorbent | pH | T (°C) | MSC (mg/g) ^a | Reference |
|---------------------|---|---------|--------|-------------------------|------------|
| Sediment | Thermally treated sediment | 3.4 | 20 | 6.3 | This study |
| | Z-0.8 | 3.4 | 20 | 38.9 | This study |
| Synthesized zeolite | Z-1.2 | 3.4 | 20 | 54.4 | This study |
| | Z-1.6 | 3.4 | 20 | 65.0 | This study |
| | Z-2.0 | 3.4 | 20 | 75.8 | This study |
| | Coal fly ash-based | 3.4 | 20 | 22.3–99.9 | [20] |
| | Activated carbon from co-mingled natural organic wastes | 3.7 | 30–45 | 43.5–46.7 | [26] |
| Carbon based | Activated carbon from coconut shell fibers | 5.0 | 10–40 | 11.0–16.1 | [27] |
| | Native saltbush | 5.0 | – | 16.3–27.0 | [28] |
| | Esterified saltbush | 5.0 | – | 5.5–7.1 | [28] |
| | Hydrolyzed saltbush | 5.0 | – | 20.8–26.2 | [28] |
| | Coir pith | 3.3 | 27 | 11.6 | [29] |
| Plant based | Carrot residues | 4.5 | 25 | 45.1 | [30] |
| | Aspergillus biomass | 5.0 | 28 | 15.6 | [31] |
| | Brown seaweed (<i>Turbinaria</i> spp.) | 3.5 | 30 | 31.0 | [32] |
| | Cork powder | 4.0 | 22 | 6.3 | [33] |
| | Wine processing waste sludge | 4.0 | 20–50 | 10.5–16.4 | [34] |
| Organic wastes | Biogas residual slurry | 2.5 | 30 | 7.8 | [35] |
| | Composite alginate–goethite beads | 2.0–4.0 | 20–60 | 8.9–30.4 | [36] |
| Alginate based | Protonated dry alginate beads | 3.5,4.5 | 25 | 57.0,77.0 | [37] |
| | Bagasse fly ash | 5.0 | 30–50 | 4.2–4.4 | [38] |
| Fly ash | Palm oil fuel ash | 3.0–6.0 | 25 | 6.9–16.4 | [39] |
| | Coal fly ash | 3.4 | 20 | 1.8–32.2 | [19] |
| | Natural zeolite | 3.0 | 27 | 6.9 | [40] |

^a Maximum sorptive capacity, measured by repeated batch equilibration method (natural and synthesized zeolite as well as coal fly ash and thermally treated sediment) or Langmuir maximum sorptive capacity (other materials).

mechanism. To examine the reversibility of Cr(III) sorbed on zeolitic materials, three kinds of reagents, all having the concentration of 1 mol/L, were employed in our desorption experiments and the results can be seen in Table 3. No desorption of Cr(III) by MgCl₂ (pH 7.0) was detected, indicating that the sorbed Cr(III) was rather stable and totally not exchangeable by other cations at neutral pH conditions. Use of NaOAc with the same molar concentration but a lower pH of 4.8 desorbed a detectable but still slight quantity (<10%) of the sorbed Cr(III). The fraction of Cr(III) released by the same solution but with a more acidic condition (pH 3.5) increased to 1/5–1/3 of sorbed Cr(III). This result suggests that the desorption of Cr(III) was highly dependent on pH, and Cr(III) sorbed was not easily released from the zeolitic materials at pH around neutral or higher even using a high ionic strength electrolyte.

Um and Papelis [41] reported that the fraction of Pb desorbed from a natural zeolite was low at high pH but increased at low pH. They attributed the stronger Pb binding at high pH to the adsorption on surface hydroxyl sites and/or the formation of surface polynuclear complexes or precipitates as a result of hydrolysis. It was documented that the pH-dependent, hydrolysable aluminol and silanol sites are located at the edges or corners of zeolite channels. Hence, for zeolitic materials used in this study, adsorption on hydroxyl sites is also possible. In the case of chromium, formation of polynuclear compounds, i.e., hydrolytic oligomers and polymers, could be caused by reactions of olation [42]. Ionic species of chromium with polymerization degree up to 100 have been identified [43]. On the other hand, precipitation as chromium hydroxide

will take place at pH values above the critical pH value, which was calculated to be 4.81 for the Cr(III) concentration of 200 mg/L by taking the K_{sp} value of Cr(OH)₃ as 1×10^{-30} . In our previous study, it was pointed out that uptake of Cr(III) by zeolite synthesized from coal fly ash involved cation exchange on negatively charged zeolite surface, adsorption on hydroxyl sites, and formation of chromium hydroxide [19,20]. Uptake of Cr(III) by each mechanism was enhanced with increasing pH. These sorption mechanisms are deemed to be true for zeolitic materials synthesized from heated sediment.

3.3. Removal of Cr(III) from wastewater

The concentrations of main cations in the wastewater (pH 3.92) are given in Table 4. The wastewater was acidic and had the Cr(III) concentration of 106 mg/L. The operations in the factory employed solely trivalent chromium and thus concentration of Cr(VI) in wastewater was not detectable. The wastewater contained predominantly high concentration of Na⁺, which was about 25 times higher than Cr(III). Compared with Na⁺, the concentrations of other cations were very low, but the concentrations of Ca²⁺ and Mg²⁺ were still comparable to Cr(III).

The results obtained in the batch process for Cr(III) uptake by zeolitic material using different doses (solid/liquid

Table 3
Percentage desorption release of Cr(III) by different electrolyte solutions (%).

| Material | MgCl ₂ (pH 7.0) | NaOAc (pH 4.8) | NaOAc (pH 3.5) |
|----------|----------------------------|----------------|----------------|
| Z-0.8 | 0 | 6.0 | 26.8 |
| Z-1.2 | 0 | 7.5 | 23.1 |
| Z-1.6 | 0 | 7.4 | 24.8 |
| Z-2.0 | 0 | 8.2 | 32.7 |

Table 4
Concentrations of the main cations in a wastewater obtained from the leather tanning factory (mg/L).

| Cation | Concentration |
|--------|---------------|
| Cr | 106 |
| Na | 2524 |
| Ca | 69 |
| Mg | 28 |
| Al | 9 |
| K | 6 |
| Fe | 3 |

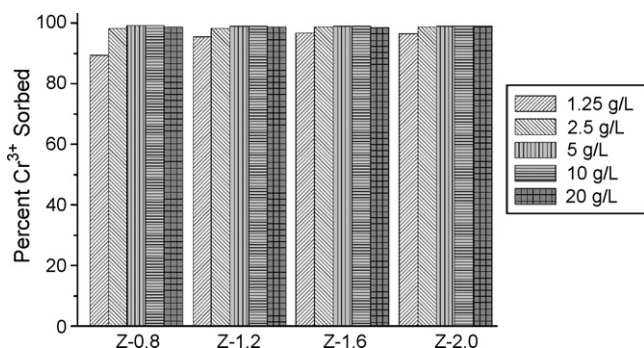


Fig. 3. The effect of zeolite dosage on uptake of Cr(III) from a wastewater obtained from the leather tanning factory.

ratio = 1.25–20 g/L) are shown in Fig. 3. Final pH values are given in Table 5. By utilizing a dose ≥ 2.5 g/L, all zeolitic materials achieved excellent removal performances, with Cr(III) uptake all exceeding 98%. This indicates that zeolitic materials synthesized from the heated sediment are promising for treating Cr(III) containing wastewater. The differences in Cr(III) removal among different zeolitic materials were observed at the solid/liquid ratio of 1.25 g/L. As stated before, the zeolitic materials were synthesized at the NaOH/sediment ratios of 0.8, 1.2, 1.6, and 2.0, respectively. The Cr(III) retention by zeolitic material was greater when higher NaOH/sediment ratio was adopted during the synthesis process. The zeolitic materials had alkaline pH values, which located within the range from 9.0 to 10.0 when in contact with doubly distilled water. As seen in Table 5, addition of zeolitic materials into the wastewater raised the pH from 3.92 to different degrees. In general, the final pH augmented with increasing dose and a high final pH was achieved when a zeolitic material was synthesized under a high NaOH/sediment ratio. Obviously, except the case of Z-0.8 and Z-1.2 with the dose of 1.25 g/L, final pH all reached above the calculated critical pH value (4.90) for the precipitation of chromium hydroxide at the initial Cr(III) concentration of 100 mg/L, resulting in almost complete removal of Cr(III).

It should be kept in mind that the wastewater contained very high concentrations of competitive cations, which could be considered an impediment to Cr(III) uptake due to the foreseeable competition for cation exchange sites in the zeolites. The high efficiencies of Cr(III) removal from wastewater by zeolitic material indicated that Cr(III) is highly competitive than other cations and thus selectively sorbed.

To verify the selectivity of Cr(III) over Na^+ and Ca^{2+} , sorptive uptake of Cr(III) by zeolitic materials synthesized from the heated sediment was tested under different background electrolyte concentration (0, 1.0 M NaCl, 1.0 M CaCl_2). The pH condition was not artificially adjusted but the final pH was determined and it was within the range of 7.8–10.0. A zeolite dose of 10 g/L was adopted. It was confirmed that Cr(III) was completely removed from solution by zeolitic materials regardless of the presence of electrolytes with the high concentration (data not shown). Similarly, Um and Papelis [41] reported that Pb had high affinity for the zeolitized tuffs and

Table 5

The equilibrium pH of the leather tanning wastewater after treatment by zeolites synthesized from thermally treated sediment.

| Sorbent dose (g/L) | Z-0.8 | Z-1.6 | Z-1.2 | Z-2.0 |
|--------------------|-------|-------|-------|-------|
| 1.25 | 4.05 | 4.69 | 5.22 | 5.63 |
| 2.50 | 6.17 | 7.49 | 8.04 | 8.10 |
| 5.00 | 8.88 | 9.15 | 9.48 | 9.65 |
| 10.00 | 9.88 | 9.86 | 10.03 | 10.19 |
| 20.00 | 10.18 | 10.11 | 10.20 | 10.24 |

was quantitatively removed at high pH even in the presence of high concentrations of NaNO_3 .

It is presumed, therefore, that zeolitic materials synthesized from thermally treated sediment are promising in the removal of heavy metals such as trivalent chromium from wastewater. In addition, the zeolitic materials may be utilized to increase pH condition and to immobilize heavy metals in polluted soils.

4. Conclusions

- (1) Zeolitic material can be synthesized from thermally treated sediment which, as a solid residue produced after decontamination of sediment by heat treatment, awaits productive reuse. The conversion process could be enhanced by use of a high NaOH/sediment ratio.
- (2) The zeolitic materials had high potential to sequester trivalent chromium from aqueous solution when compared with the raw thermally treated sediment and other materials reported previously. The maximum amount of Cr(III) sorption by the zeolitic materials, determined by repeated batch equilibration method, ranged from 38.9 to 75.8 mg/g.
- (3) Even in the presence of high concentrations of other alkali and alkaline-earth cations such as Na^+ and Ca^{2+} , the zeolitic materials could highly selectively sorb Cr(III) from wastewater. The sorbed Cr(III) on zeolitic materials was stable and it was unlikely to be desorbed by other cations at high pH, but the desorption increased at increasingly acidic conditions.
- (4) Thermally treated sediment could be converted to zeolitic material which could then be utilized in the removal of trivalent chromium from wastewater or in the immobilization of heavy metals of polluted sites.

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