PREPARATION AND EVALUATION OF A Ce(IV)-La(III) BINARY HYDROXIDE ADSORBENT AS RECOVERY OF WASTE CERIA POWDER FROM GLASS POLISHING PROCESS FOR EFFECTIVE ARSENIC REMOVAL

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Abstract

In this paper Ce(IV)-La(III) binary hydroxide adsorbent, herein referred to as CLH adsorbent, which is a recovery of waste ceria powder from glass polishing process, is used as a novel adsorbent for removing inorganic arsenic (As) from water. The CLH adsorbent is prepared using a combined acid and heating treatment method, which involves refluxing the waste ceria powder in 2 M H_2SO_4 , adding NaOH for complete precipitation, filtering, and drying at 80–90°C. The adsorption of As onto CLH is studied as a function of adsorbent dose, contact time, and pH. Within the range of tested (pH 4–11), the optimal pH for As(V) and As(III) adsorption is 4 and 8, and close to 100% removal can be achieved at adsorbent dose of 2.0 g L⁻¹, fixed ionic strength (0.01 M NaNO₃), and room temperature (25±1°C) for an initial As concentration of 10 mg L⁻¹ within 6 h irrespective of the initial pH, and the time required to reach pseudoequilibrates changes with the initial pH. The CLH adsorbent appears to be an efficient and cost-effective material for both As(III) and As(V) removal. The experiment provides also a feasible and promising way to use waste as a material for the treatment of other wastes or contaminants from the point of recycling.

Key words - Arsenic removal, waste ceria, groundwater treatment, adsorption, Ce(IV)-La(III) binary hydroxide

Introduction

Arsenic, a relatively scarce but ubiquitous metalloid element, ranks 20th in natural abundance with an average concentration in most rocks of 0.5–2.5 mg/kg (Mohan et al. 2007), and is classified by the International Agency for Research and Cancer (IARC) as a human carcinogen (IARC, 1980; Brown and Ross, 2002) due to its toxicity and carcinogenicity. The average concentration of As is less than 2 μ g L⁻¹ in streams, and generally less than 100 μ g L⁻¹ in groundwater (Bhattacharya et al., 2007). The presence of naturally occurring high levels of arsenic in the groundwater has been found in many regions of

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Bangladesh, India, Vietnam, USA and other countries of the world (Mandal and Suziki, 2002; Smedley and Kinniburgh, 2002; Wang and Xu, 2005; Bhattacharya et al., 2007). Long term uptake of drinking water containing arsenic causes cerebrovascular disease, diabetes mellitus and hyperkeratosis but can also lead to lung, liver, kidney, and skin cancer (Zhang et al., 2007). Chronic arsenism poses a serious health problem in China also. About 14.6 million people, mainly distributed in the northwest China including Inner Mongolia, Xinjiang, are exposed to drinking water containing arsenic with a concentration of 300 µg L^{-1} or higher (Zhang et al., 2005). Due to the serious effects of arsenic on human health, World Health Organization (WHO) recommended 10 μ g L⁻¹ as the guideline for arsenic in drinking water in 1993 (WHO, 1993), and the Chinese Environmental Protection Agency also promulgated 10 μ g L⁻¹ as its new arsenic standard for drinking water which has become effective from January 2007.

Inorganic As in drinking water provides the most significant form of human exposure. Soluble As occurs in natural waters only in the As(V) (arsenate) and As(III) (arsenite) oxidation states. Arsenate is the most stable form under aerobic conditions, existing as the pHdependant deprotonated oxyanions of arsenic acid $(H_2AsO_4^- \text{ and } HAsO_4^{2-})$ at natural pH (Ferguson and Gavis, 1972), whereas As(III) is the dominant arsenic in groundwater (Smedley and Kiniburgh, 2002). Arsenite is a neutral species at natural pH values that lacks electrostatic attraction, and hence there are fewer adsorption sites available for arsenite than for arsenate (EPA, 2000). Consequently, arsenite is difficult to remove from water. As(III) is much more toxic and more mobile than As(V). Although the conversion of As(III) to As(V) in oxygenated water is thermodynamically favored, the rate of the transformation may take days, weeks, or months depending on specific conditions (Edwards, 1994).

Many different methods such as precipitation, coprecipitation, ion-exchange, ultra filtration, reverse osmosis, and adsorption have been used for arsenic removal. The adsorption process is considered to be one of the most promising technologies because the system can be simple to operate and cost-effective (Jang et al., 2006). However, most adsorbents are effective for As(V), but fail in case of As(III) (Frank and Clifford, 1986; Jekel, 1994; Driehaus et al., 1994). Among a variety of available materials for arsenic removal, hydrous oxides of cerium and lanthanum, the most abundant resource of rare earth metals, are reported to have high adsorption capacity for As(III) and As(V) simultaneously (Imai et al., 1987; Tokunaga et al, 1999).

Rare earth metals are today used, with an increasing demand, in the production of e.g. ceramics, batteries and pharmaceuticals. Development of new applications for rare earth metals are of great interest e.g. as diesel fuel additive, cement additive, flexible superconductive tape. At present, the Chinese glass industry uses more than ten thousand tons of ceria in glass polishing annually. Waste ceria polishing powder is a waste by-product produced in the glass polishing process; most of them are discarded with wastewater sludge without further use. As Table 1 shows the main components of waste ceria glass polishing powder are CeO₂ and La₂O₃. Considering the fact that the hydroxide form of both Ce and La exhibit high affinity to As(III) and As(V) (Imai et al., 1987; Tokunaga et al., 1997), the idea to prepare an ad-

sorbent for arsenic removal by converting the oxide forms of Ce and La to their hydroxide forms is of benefit from both the water purification and waste solid reuse points of view.

To our knowledge, no research results on the Ce-La binary hydroxide as recovery of waste ceria glass polishing powder for arsenic removal have been reported in the literature. Therefore, the main objectives of this research were: (1) to develop a means of converting waste ceria polishing powder into a Ce-La binary hydroxide adsorbent for effective arsenic removal; and (2) to evaluate its arsenic adsorption potential and to examine the influence of adsorbent dose, contact time, and solution pH on arsenic removal.

Materials and Methods

Materials

All chemicals were analytical grade and purchased from Beijing Chemical Co. (Beijing, China). Waste ceria polishing powder was taken from a glass manufacturing plant. The As(III) and As(V) stock solutions were prepared with deionized water (DW) using NaAsO₂ and NaHAsO₄·7H₂O, respectively. Arsenic working solutions were freshly prepared using arsenic stock solutions and DW. The concentrations of arsenic species were always given as elemental As concentration in this study.

Adsorbent Preparation

The Ce-La binary hydroxide adsorbent was prepared according to the following procedure: waste ceria polishing powder from a glass manufacturing plant was first activated through acid treatment by heating a fixed portion of dry waste ceria polishing powder with 2.0 mol/L H_2SO_4 solutions under continuous stirring until complete dissolution. Under vigorous magnetic-stirring, a 2.0 mol/L NaOH solution was slowly added into the

Table 1. Chemical composition of waste raw material ceria polishing powder used in this study.

Constituent	wt %	Constituent	μg g ⁻¹	
CeO ₂	51	Cd	n.d.	
La ₂ O ₃	32	Pb	418	
Pr_6O_{11}	2	Cu	99	
Nd ₂ O ₃	5	Zn	38	
SrO	< 0.5	Ni	8	
SiO ₂	< 0.5	Fe	5700	
Al_2O_3	1.5	Mn	110	
CaO	5.3	Cr	n.d.	
BaO	1.9	V	n.d.	

resultant Ce(IV) and La(III) solution to bring the solution pH in the range of 11 and 12. After addition, the formed suspension was continuously stirred for 1 h, aged at room temperature for 12 h and then washed repeatedly with deionized water to remove the residual alkali. The suspension was filtrated and dried over night at a temperature below 100°C. The dry material was ground to obtain a fine dark-yellow powder, sieved to constrain the grain size to less than 0.250 mm and stored in desiccator for use.

Adsorbent Characterization

Specific surface area of the CLH (CLH is the adsorbent subjected to the above-mentioned treatment) was measured by nitrogen adsorption according to the Brunauer-Emmet-Teller (BET) protocol on a Micromeritics Flow-Sorb III equipment. Particle size of the adsorbent was determined by a Mastersize 2000 (Malvern Co.). The point of zero charge (pHzpc) was evaluated according to the method proposed by Kinniburgh et al (1975) that described as follows: a mass of 1.00 g of finely ground CLH powder was suspended in 100 mL of 0.01 M NaNO₃ for 24 hours to allow partial rehydration of the surface. Aliquots of the suspensions were then adjusted to various pH values with NaOH or HNO₃. After 60 min for equilibration, the initial pH was measured; then 1.0 g of NaNO₃ was added to each aliquot to bring final electrolyte concentration to about 0.45 M. After an additional 60 min, the final pH was measured. The results, plotted as ΔpH (final pH – initial pH) against final pH, yield the pHzpc as the pH at which $\Delta pH = 0$.

Batch Adsorption Tests

Adsorption tests were performed in 100 mL polyethylene vessels to evaluate arsenic removal capability. A matrix electrolyte of 0.01 M NaNO₃, prepared by dissolving reagent grade NaNO₃ in DW, was used for all adsorption experiments. For all tests, the vessels were capped tightly and were shaken on an orbit shaker (150 rpm) at room temperature (25±1°C) until pseudoequilibrium was reached. After completion of the treatment, all test mixtures were filtered through a 0.45µm membrane filter. Total As in the filtered solution was determined. The quantity of adsorbed arsenic was calculated by the difference of the initial and residual amounts of arsenic in solution divided by the weight of the adsorbent.

To evaluate the effect of adsorbent dosage, test solutions (50mL) having pre-determined initial As concentrations prior to adding CLH at amounts required to obtain 0.05, 0.1, 0.2, 0.3, 0.5, 0.7, 1.0, 1.5, 2.0, 2.5, and 3.0 g L^{-1} adsorbent dosages. The natural pseudo-

equilibrium pH of the CLH is about 6.9–7.2 and the CLH dosage effect was tested at this pH.

To test the effect of contact time, defined amount of As(III) and As(V) stock solution was added in a 500 mL polyethylene vessel containing 400 mL 0.01 M NaNO₃ solution, CLH was added to obtain a 2.0 g L⁻¹ suspension. Three experiments were run with As(III) and As(V) each involving an initial pH of 4.0, 8.0, and 11.0. The suspension was mixed with a magnetic stirrer, and the pH was maintained at designated values throughout the experiment by addition of the acid and base solutions. Approximately 5 mL of aliquots were taken from the suspension at the following intervals: 0.083, 0.167, 0.25, 0.5, 0.67, 1, 2, 4, 6, 12, 18 and 24 h of reaction.

Experiments to determine the effect of solution pH values on arsenic removal were performed by adding 100 mg of the adsorbent sample into the vessel, containing 50 mL of 250 mg L^{-1} arsenic solution. The pH of the solutions was adjusted every 3 h with HCl and NaOH to designated values in the range of 4–11 during a 24 h shaking process.

Analytical Methods

Total As concentrations were determined using a hydride generation-atomic fluorescence spectroscopy (HG-AFS, SK-2002 Rayleigh, Beijing Ruili Analytical Instrument Co., Ltd. China). Prior to analysis, the aqueous samples were acidified with concentrated HCl in an amount of 1 %, and stored in acid-washed glass vessels. All samples were analyzed within 24 h of collection. The experiments were performed in triplicate and the mean values were considered. The blank experiments showed no detectable As(III) and As(V) adsorbed on the walls of the vessel.

Results and Discussion

Effect of Preparation Conditions on Arsenic Adsorption Capacity

Table 1 shows that waste ceria polishing powder contains ceria and lanthanum oxide as majorities with other oxides as minor or trace compositions. Adsorption capability may be attributed to these constitutes. The key goal of waste ceria polishing powder processing in the present research was to convert the relatively non-reactive oxides (in the form of CeO₂ and La₂O₃), which mainly makes up the raw polishing powder, into hydroxide form which readily reacted with aqueous arsenic.

Results of standard adsorption tests of As(III) and As(V) carried out using the resultant CLH produced by acid and then alkali treatment of waste ceria polishing powder under different acid treating conditions are



Figure 1. Effect of acid treating condition of waste raw ceria polishing powder on arsenic adsorption capacity; reaction time 24 h; temperature, 25°C; CLH dosage 2.0 g L^{-1} ; As conc. 250 mg L^{-1} , pH 8 for As(III); pH 4 for As(V) adsorption.

shown in Fig. 1. Heating the raw waste polishing powder in H_2SO_4 solution increased significantly the adsorption capacity for both As(III) and As(V) until a steady stage was reached at a certain concentration and then the capacities remain unchanged despite the increase of acid concentration. A working H_2SO_4 solution concentration of 2.0 mol·L⁻¹ was therefore selected enabling a sufficiently high adsorption capacity for arsenic anions as compared to that of the untreated raw material (refers to CT in Fig.1). The maximum adsorption capacity for the CLH that was prepared at the optimized conditions was 87 mg g⁻¹ for As(III) and 113 mg g⁻¹ for As(V), respectively, e.g. 67 times and 26 times higher than those of the raw materials.

Fig. 2 shows that the resultant CLH exhibits unchanged adsorption capacities for arsenic anions as the drying operation performed below 100°C. The adsorption capacity decreases gradually with the increase of dry temperature of above 100°C. A drying temperature around 80–90°C was chosen and used throughout the work.

Characterization of Adsorbent

The medium mass particle size of the powdered adsorbent was 68.7µm. The BET surface area of the adsorbent was 58 m² g⁻¹. The pHzpc of CLH was determined based on the fact that for hydrous oxide, increasing the concentration of an indifferent electrolyte, in this case NaNO₃, increases the magnitude of the surface charge by causing adsorption or desorption of H⁺ or OH⁻ and only at the pHzpc is there no change in pH (Kinniburgh et al., 1975). The obtained pHzpc value was 7.3, somewhat greater than that of the pure CeO₄ · xH₂O powder (pHzpc = 6.7, Zhang et al, 2005).



Figure 2. Effect of drying temperature of resultant Ce-La (CLH) adsorbent on arsenic adsorption capacity; reaction time 24 h; temperature, 25°C; CLH dosage 2.0 g L^{-1} ; As conc. 250 mg L^{-1} , pH 8 for As(III); pH 4 for As(V) adsorption.

Effect of Adsorbent Dose

The effect of the CLH dose on the adsorption of As(III) and As(V) at an initial arsenic concentration of 10 mg L⁻¹, fixed ionic strength (0.01 M NaNO₃), contact time of 24 h, and solution pH 7.0 is depicted in Fig. 3. The results indicated that for a fixed initial arsenic concentration, the arsenic removal percentages increased with an increasing adsorbent dose up to certain value and then there was no further increase in adsorption. As seen from Fig. 3, 2.0 g L⁻¹ of CLH was sufficient for quantitative adsorption of As(III) and As(V), and this dosage value was selected in the present batch adsorption studies.



Figure 3. As(III) and As(V) adsorption as a function of the CLH dosage with reaction conditions: initial concn., 10 mg L^{-1} ; ionic strength, 0.01M NaNO₃; contact time, 24 h; temperature, 25°C; initial pH 7.0.



Figure 4. Effect of contact time on the adsorption of (a) As(III) and (b) As(V) by CLH suspension at three different pH, with reaction conditions. initial concn., 10 mg L^{-1} ; ionic strength, 0.01M NaNO₃; CLH dosage, 2.0 g L^{-1} ; temperature, 25°C.

Effect of Contact Time

Fig. 4(a) and 4(b) show the effect of contact time on As(III) and As(V) adsorption onto CLH, respectively, at an initial As concentration of 10 mg L⁻¹, fixed ionic strength, for the selected initial pH 4.0, 8.0 and 11.0. It was observed that with a fixed amount of CLH, the removal of arsenic increased with contact time and then to reach equilibrium after 6 h for As(V) and 9 h for As(III), respectively, the residual As concentration obtained in all cases satisfies the 10 µg L⁻¹ (WHO provisional guideline for As). However, the time to establish adsorption equilibria was highly affected by the initial pH values. It was observed that As(V) adsorption reaches a plateau (ca. 96% removal) at 1, 3 and 6 h for pH 4.0, 8.0 and 11.0, respectively. In the case of As(III), a contact time of 3, 5 and 9 h was needed for pH 8.0, 4.0 and 11.0, respectively.

The adsorption rate of As(V) was rapid with ca. 60 % completion after ca. 1 min of shaking at an initial pH of 4. In such acidic condition, the residual As concentration of < 1.0 mg L⁻¹ As was attained within 5 min. The As(V) adsorption rates decreases with increasing pH. Significant amounts of As(V) anions were adsorbed in 20 min at pH 8. At a pH of 11, As(V) concentration decreased to < 0.1 mg L⁻¹ As. At an initial pH of 8, a decrease of As(III) was found from 10 to < 1.0 mg L⁻¹

As in about 1 min and to $< 0.01 \text{ mg L}^{-1}$ As in 2 h. The adsorption rate decreased somewhat at an initial pH of 4, whereas a significant decrease in adsorption rate was found at an initial pH of 11.

Effect of Solution pH

Fig. 5 reveals that the optimal adsorption studied in the equilibrium pH range between 4 and 11 at an initial arsenic concentration of 250 mg L⁻¹, fixed ionic strength, adsorbent dose of 2.0 g L⁻¹, and contact time of 24 h. The adsorption capacities are 87 mg g⁻¹ at the pH 8.0 for As(III) and 113 mg g⁻¹ at the pH of 4.0 for As(V). The obtained q_m values of CLH compare favorably with those obtained using other adsorbents (Table 2), indicating that CLH was effective for both As(V) and As(III) removal. This result met the objective of developing such an adsorbent since As(III) is more toxic and more difficult to remove from water than As(V).

The maximum of As(III) adsorption was observed at about pH 8.0. Adsorption decreases at both lower and higher pH values. Variations in As(V) adsorption at the pH range 4.0–6.0 were found to be slight. As(V) adsorption decreased sharply above pH 6.0. In the adsorption studies of As(III) by amorphous ferric hydroxide (Pierce and Moore, 1982), granular ferric hydroxide



Figure 5. Effect of pH on the adsorption of As(III) and As(V) by the CLH adsorbent. Initial As(III) and As(V) concentrations are both 200 mg $\cdot L^{-1}$, CLH dosage 2.0 g $\cdot L^{-1}$, reation time 24 h, temperature 25 °C.

(Thirumavukkarasu et al., 2003), and iron-coated sand (Gupta et al., 2005), almost similar results were reported regarding the range of pH for maximum adsorption. The maximum adsorption of As(III) and As(V) was reported for red mud at pH 7.6 and 4.0 (Altundoğan et al., 2000), respectively.

Adsorption Mechanisms

Both As(III) and As(V) anions were found to be adsorbed onto CLH in a wide pH range including neutral and basic conditions, where the pH values is higher than pHzpc, indicating that the removal of arsenic from aqueous solution by adsorption is highly dependent on pH, and is affected by the surface charge of the adsorbent, degree of ionization, and nature of arsenic speciation. It appears that a formation process of inner-sphere complexes rather than a purely electrostatic adsorption should be the major driving force in the adsorption of arsenic anions. The results of batch adsorption observations give support to this hypothesis.

In the pH range of 4-9.5, the predominant As(III) species available are H₃AsO₃ and H₂AsO₃⁻. At pH 8.0, H₃AsO₃ is highly predominant among total arsenite species; but with increase in pH, H₃AsO₃ is getting drastically reduced and other negative species H₂AsO₃⁻ and $H_2AsO_3^{2-}$ become dominanting (Thirunavukkarasu et al., 2003). Since the CLH surface is positively charged up to pH 7.3 (pHzpc), arsenic may be adsorbed through an electrostatic attraction between the neutral species and the positively charged surface sites. The consistent adsorption of As(III) up to pH 7 may be due to van der Waal force between neutral arsenite species H₃AsO₃ and the adsorbent (Lin and Wu, 2001). The binding of neutral arsenite species to the available partially positive surfaces may contribute to the removal. Since As(III) species exists predominantly as H₃AsO₃ at pH less than 9.2, the observed high adsorption of As(III) at pH > pHzpc in the range of 7.3-8.0 suggests arsenic adsorption predominantly occurred through surface complexation reactions than by electrostatic interactions.

The formation process of inner-sphere complexes between the no charged H3AsO30 and adsorbent surface may also be achieved at pHs > pHzpc provided the undissociated acid gives a proton to the hydroxyl group on the surface to form H₂O that can be readily displaced by the anion (;Ahemd, 1966). The facts that rapid adsorption of As(III) occurred in neutral condition and the adsorption maxima was observed at pH 8 might be attributed to the difference between the energy release upon adsorption and the energy required to dissociate the acid is at a maximum (Pierce and Moore, 1982). At higher pH, an increasing amount of H₂AsO₃⁻ species is produced, and above pH 8.0 the decrease in adsorption may be attributed to the increasing electrostatic repulsion between the negative arsenite species. Arsenic adsorption capacity and rate reduced at a pH > 9. In such

Adapahant	Adsorption capacity (mmol g ⁻¹)		D of	
	Max. As(III)	Max.As(V)	Kci.	
Ce-La composite (CLH)	84.1 (pH 7.0)	89.9 (pH 7.0)	Present work	
Fe-Mn composite	132.6 (pH 5.0)	67.4 (pH 5.0)	Zhang et al. (2007)	
MnO ₂	9.7	7.5	Lenoble et al. (2004)	
Geothite	/	39.7 (pH 3.3)	Matis et al. (1997)	
$Al_2O_3/Fe(OH)_3$	9.0 (pH 6.6)	36.7 (pH 6.6)	Hlavay and Polyák (2005)	
Fe-Mn mineral material	12.0 (pH 6.6)	6.7 (pH 6.6)	Deschamps et al. (2005)	
TiO ₂	32.2 (pH 7.0)	41.2 (pH 7.0)	Bang et al. (2005)	

Table 2. Maximum Arsenic adsorption capacities of some adsorbent system.

alkaline conditions, $H_2AsO_3^-$ is the predominant species and adsorbent surface becomes negatively charged. Therefore, As(III) adsorption capacity and adsorption rate reduced as all the components have negative charges and thus repel each other as As(III) adsorption must compete with electrostatic repulsion.

In the case of As(V), $H_2AsO_4^-$ is the predominant species at pH 4, and, apparently, the major species being adsorbed. The CLH surface has a net positive charge and adsorption is facilitated by electrostatic interaction, the removal is rapid and adsorption capacity is high because electrostatic interaction can readily take place in conjunction with specific adsorption (Fig. 4(a)). At a pH of 8, more than 50% of As(V) anions are negative two charges (HAs O_4^{2-}) and less than 50% negative one charges (H2AsO4). The adsorbent surface is already negatively charged. Because all the components have negative charges arsenate adsorption must compete with electrostatic repulsion. The formation of inner-sphere complexes is usually slower than electrostatic interactions since it may be site specific and ligand orientation may be necessary. Therefore, adsorption process of As(V) was slow and adsorption capacity reduced.

Arsenate anions have mostly negative two charges and a few negative three charges at pH 11. The adsorbent surface becomes more negatively charged. The negatively charged components would thus repel each other; the adsorption of As(V) have to compete with electrostatic repulsion. Consequently, As(V) adsorption capacity is suppressed and adsorption rate is significantly decreased.

During the sorption experiments, cerium and lanthanum was beyond detectable in the finishing solution at pHs within the range 4–11, where As(III) and As(V) sorption occurred, indicates that the mechanism the precipitation of an Ce(IV)/La(III) arsenate or Ce(VI)/ La(III) arsenite is not involved in the removal of both As(V) and As(III). Taking into account (i) the characteristics of CHL, (ii) the presence of functional groups on the sorbent surface (mainly free hydroxyls) and considering (iii) the nature of arsenic species present in solution at the working pH, the mechanisms for As(III) and As(V) were proposed as follows:

For As(V) and As(III) adsorption, it is supposed that two different mechanisms can contribute to sorption: (i) non-specific coulombic interactions between As(V) species and the positively charged functional groups on the sorbent surface and (ii) coordination of As(V) and As(III) species onto metal (hydr)oxides with the formation of inner-sphere compounds. Such a sorption mechanism has been reported in the literature, as responsible for As(III) and As(V) sorption onto an aquifer material of complex mixture mineralogical nature (Carrillo and Drever, 1998).

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Conclusions

The present research demonstrated that waste ceria polishing powder could be converted into a material that has high adsorption capacity for arsenic in wastewaters. The CLH adsorbent is prepared using a combined acid and heating treatment method, which involves refluxing the waste ceria powder in 2 M H₂SO₄, adding NaOH for complete precipitation, filtering, and drying at 80-90°C. The resultant CLH adsorbent has promising potential for use as an unconventional adsorbent that is comparable with commonly used pure adsorbents for As removal (e.g. Fe- and Mn- hydroxides), and it may well be suitable as a new adsorbent for As removal during water treatment. As(III) and As(V) species can be efficiently removed at three selected initial pH values (4, 8, 11), and a dosage of 2.0 g L^{-1} CLH can be enough to achieve the 10 µg L⁻¹ (WHO provisional guideline for As) when the initial As concentration is 10 mg L^{-1} , which is much higher than the concentration of about 100–300 μ g L⁻¹ that are typically found in As contaminated water used for human consumption and, consequently, the operational life expectancy of a CLH-based sorption system used in drinking water treatment would be high. Therefore, by using the CLH, recovered from waste ceria glass polishing powder, as adsorbent for arsenic a double goal can be achieved: the valorization of an industrial solid by-product whose management involves an important economical cost and the removal of arsenic from aqueous solutions, in either As(III) or As(V) form, through low-cost environmentally friendly technologies.

Both As(III) and As(V) anions seem to be removed principally by the formation of inner-sphere complexes on the CLH surface as revealed by the adsorption experiments. However, more experimental work is required to evaluate the possible use of CLH under continuous flow conditions. More work on the mineralogy of the CLH will also be required to determine whether it is possible to enhance its As sorption capacity further by modifying production conditions to make use of the enhanced As binding capacity. Once both the physical and chemical conditions for the production of CLH are optimized, then it will be necessary to conduct a full cost-benefit analysis to compare it to alternative reagents.

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