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Removal Of Arsenic From Water Using Iron-Coated Pomelo Peel (ICPP)

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Abstract. This study investigated the removal of arsenite (As(III)) and arsenate (As(V)) in aqueous solution using iron-coated pomelo peel (ICPP). Batch adsorption experiments were performed to evaluate the effects of initial pH values (2.0–10), contact time (1–1440 minutes), initial concentration (0.05–5 mg/L) on the As(III) and As(V) removal capacity by ICPP. The Langmuir maximum adsorption capacities of ICPP of As(III) and As(V) at pH 7.0, and 25 °C were 1.51 mg/g and 1.64 mg/g, respectively. The capacities were significantly higher than that of raw pomelo peel (PP) material at the same condition (q_{max} As(III) = 0.032 mg/g and q_{max} As(V) = 0.036 mg/g). Adsorption kinetics data fitted well with the Elovich model and the adsorption process quickly reached an equilibrium at around 120 min. The results shows that the As(III) and As(V) adsorption performance of ICPP were much better than that of PP, granular activated carbon (GAC) and many iron-based adsorbents. Thus, ICPP has potential as a filter media for efficiently removing toxic arsenic ions from water.

Keywords: Arsenic removal; Adsorption; Iron-coated pomelo peel; Water treatment.

1. Introduction

Arsenic (As) is a highly toxic element and is released to groundwater by natural processes (including weathering processes, mainly from weathering of sulphide minerals; biological activities; volcanic activities) and/or anthropogenic activities (including mining activities, leaching of wastes, wastewaters, etc.) (Smedley and Kinniburgh, 2002). Numerous water treatment technologies have been developed to remove As from contaminated waters, such as adsorption, biological treatment, and membrane-related processes. Of these technologies, adsorption is considered to be the best option at a decentralized scale due to its high removal efficiency, simplicity in design, cost-effectiveness, and minimal secondary waste generation (Nguyen et al., 2020a).

Among existing adsorbents, adsorbents derived from fruit waste have been considered to be promising media for efficient removal of As from water due to their environmental friendliness, low cost, local availability, and sustainability (Bibi et al., 2017; Khaskheli et al., 2011; Shakoor et al., 2018).

In this study, iron-coated pomelo peel (ICPP) material was modified by coating the raw pomelo peel (PP) with iron (Fe) to enhance the adsorption capacity toward arsenite (As(III) and arsenate (As(V)). To the best of our knowledge, there is no study on modified PP for removing both arsenite (As(III) and arsenate (As(V)). Therefore, this study aims to evaluate the performance of ICPP on As(III) and As(V) removal from synthetic water through batch studies under different conditions ((i.e., pH solution, contact time, and initial As concentration).

2. Materials and methods

2.1. Preparation of adsorbent

The iron-coated pomelo peels (ICPP) were produced based on the previously described modification method by Nguyen et al. (2020b), which includes the following steps: First, 50 g dried raw PP of size 0.25–5 mm was added into a 150 mL solution of 0.1 M $FeCl_3.6H_2O$. The pH value of the mixture solution was adjusted to approximately 7.0. The mixture was then shaken at 160 rpm for 48 h at room temperature (25 ± 1 °C). To enhance the level of coating, the above process was repeated three times. After the first time coating, the resulting coated material was separated from the mixture solution and dried at 70 °C for 48h. The material was then washed with deionized water several times till the filtrate did not contain the brown fraction. The materials were dried again at 70 °C for 24h and used for the second and third coating. After three-times coating with iron, the ICPP was obtained and stored in airtight containers.

2.2. Batch adsorption experiment

All batch adsorption experiments were carried out by adding 0.05 g of adsorbents into Erlenmeyer flasks containing 50 mL As(III) and As(V) solutions. The flasks were sealed, placed on a shaker and shaken at 160 rpm at 25 °C for 1440 min. The effect of solution pH on As removal by ICPP was investigated at different pH values (from 2–10) with solutions containing 0.5 mg/L As(III) or As(V). Adsorption isotherm studies were conducted with both PP and ICPP adsorbents under different initial As(III) or As(V) concentrations, from 0.05 to 5 mg/L at initial pH 7.0. Kinetic study of ICPP was conducted at different intervals (from 1 to 1440 minutes). The solutions in the flasks had initial As(III) and As(V) concentrations of 0.5 mg/L and pH of 7.0.

After pre-determined sharking times, the liquid samples were filtered through a 0.45-µm filter and the residual As in filtrate samples were analyzed by an inductively coupled plasma optical emission spectrometry (ICP-OES 7300 Perkin Elmer). The pH value of the point of zero charges was studied by the drift method as reported in the literature (Nguyen et al., 2020a).

3. Results and discussions

3.1. Effect of pH on the adsorption process

The effect of pH values on the As(III) and As(V) removal process by ICPP is shown in Figure 1. The results show that the adsorption capacity of ICPP toward As(V) was significantly affected by the solution pH changing from 2 to 10. Specifically, the adsorption capacity of ICPP decreased when the solution pH values increased. While effect of pH on As(III) removal by ICPP was less than that on As(V). Notably, ICPP exhibited a higher adsorption capacity toward As(V) than As(III) (Figure 1).

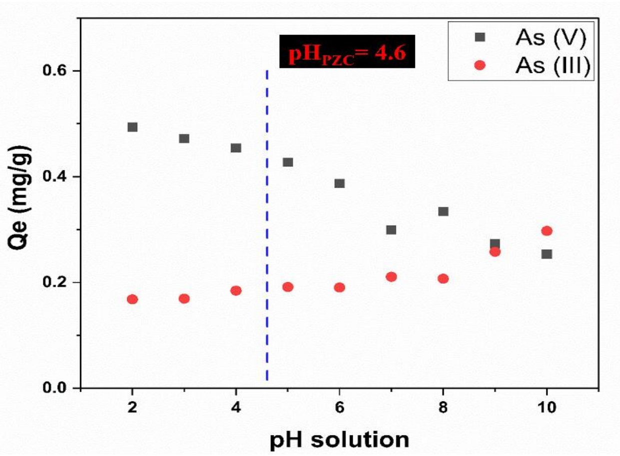

Figure 1. Effect of pH on the adsorption of As(V) and As(III) on ICPP

The highest As(V) removal efficiency of ICPP was obtained under an acidic environment (pH = 2.0, 3.0, 4.0). The reason is that ICPP has a positive surface charge at these pH values (pH_{PZC} of ICPP was 4.6) whereas As(V) species mostly exist in three primary anionic forms: $H_2AsO_4^-$ (within the pH range of 3.0 to 6.0) and divalent $HAsO_4^{2-}$ (pH range of 7.0–11) (Smedley and Kinniburgh, 2002). It indicates that the adsorption of As(V) onto ICPP was favorable through the electrostatic attraction mechanism. In contrast, As(III) mainly exists in the form of no charge ($H_3AsO_3^0$) within the pH ranges of 1.0 to 9.0 (Smedley and Kinniburgh, 2002).

3.2. Adsorption kinetics

Figure 2 shows the effect of contact time on the removal efficiency of As(III) and As(V) by ICPP at 25 °C. The reaction between ICPP and adsorbate increased rapidly in the first contact time of 30 min for both As(III) and As(V). The adsorption process has achieved equilibrium at around 120 min. In this work, three kinetic models—pseudo-first-order (PFO), pseudo-second-order (PSO), and Elovich models were used to describe the adsorption kinetics. Table 1 shows the relevant kinetic parameters for As(III) and As(V) adsorption. As can be seen from Table 1, the adsorption kinetics data were best fitted with the Elovich model (R^2 = 0.97 and 0.99 and χ^2 = 3.2×10^{-4} and 5.2×10^{-4}).

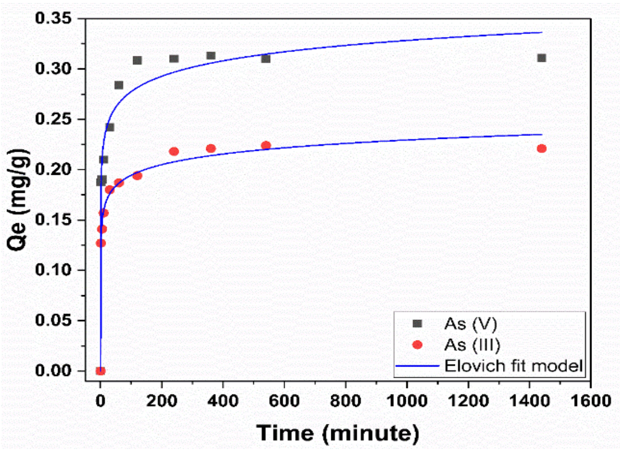

Figure 2. Adsorption kinetic for As (V) and As (III) adsorption onto ICPP

Table 1. Kinetic parameter for As (V) and As (III) uptake by ICPP

	PFO model				PSO model				Elovich model			
	q_e	k_1	χ^2	R^2	q_e	k_2	χ^2	R^2	α	β	χ^2	R^2
As(V)	0.276	1.075	0.002	0.79	0.292	2.977	0.001	0.88	63.58	45.29	3.2×10^{-4}	0.97
As(III)	0.194	0.990	8.042	0.83	0.204	4.656	4.514	0.90	54.99	65.81	5.2×10^{-4}	0.99

Note: q_e (mg/g); k_1 (1/min); k_2 [g/(mg×min)]; α [mg/(g×min)]; and β (mg/g).

3.3. Adsorption isotherm

In this work, the Langmuir and Freundlich models were applied to estimate the maximum adsorption capacities and describe the adsorption behavior of As(III) and As(V) onto ICPP and PP adsorbents. The adsorption isotherm parameters for this experiment are shown in Table 2. The results show that the experimental data of adsorption equilibrium was well fitted with two models because of the high R^2 and low χ^2 values. The maximum adsorption capacity of ICPP toward As(V) (q_{max} = 1.64 mg/g) was remarkably higher than that of PP toward As(V) (q_{max} = 0.036 mg/g). The maximum adsorption capacities of ICPP and PP toward As(III) were 1.51 mg/g and 0.032 mg/g, respectively. The maximum adsorption capacity of ICPP towards As(III) and As(V) was higher than that of PP, granular activated carbon and many iron-based adsorbents reported in the literatures (Table 3).

Table 2. Isotherm adsorption parameters for As(V) and As(III) uptake onto ICPP and PP

	Langmuir model				**Freundlich model**			
	q_{max}	K_L	χ^2	R^2	K_F	n_F	χ^2	R^2
	(mg/g)	(L/mg)	—	—	(mg/g)/(mg/L)^n	—	—	—
ICPP								
As(V)	1.64	1.15	0.04	0.87	0.74	0.52	0.03	0.90
As(III)	1.51	1.20	0.02	0.92	0.69	0.53	0.02	0.93
PP								
As(V)	0.036	5.129	2.9×10^{-6}	0.98	0.026	0.27	2.2×10^{-6}	0.88
As(III)	0.032	7.305	2.0×10^{-6}	0.98	0.024	0.24	3.0×10^{-6}	0.79

Table 3. Langmuir maximum adsorption capacity (q_{max}) for As (III) and As (V) of different adsorbents

	C_o	q_{max} (mg/g)		References
	(mg/L)	As(III)	As(V)	
ICPP	*0.05–5*	***1.51***	***1.64***	***This study***
PP	*0.05–5*	***0.032***	***0.036***	***This study***
Iron-loaded walnut shell	0.1–5	-	1.24	Duan et al. (2017)
Iron oxide amended rice husk char	0.1–2.5	-	1.46	Cope et al. (2014)
Luffa fiber	0.5	-	0.035	Nguyen et al. (2020b)
Granular activated carbon	0.1	-	1.01	Kalaruban et al. (2019)
Iron coated granular activated carbon	0.1	-	1.43	Kalaruban et al. (2019)
Fe-exchanged natural zeolite	0.1–20	0.1	0.05	Li et al. (2011)

4. Conclusions

This study shows that ICPP has a high adsorption capacity toward As(III) and As(V). The adsorption process of As(V) onto ICPP adsorbent was significantly affected by the pH solution. The data of kinetic adsorption were well described by the Elovich model. The maximum adsorption capacities of As(III) and As(V) onto ICPP were 1.51 mg/g and 1.64 mg/g, respectively, which is higher than that of raw PP and many other adsorbents.

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