Adsorption of cadmium and lead in wastewater by four kinds of biomass xanthates

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ABSTRACT

This study determined the adsorption of Cd^{2+} and Pb^{2+} (100 mg·L^{-1} of each) in simulated wastewater by biomass xanthates made from starch, chitosan, wheat stalk and corn stalk. The results showed that the adsorption efficiency of Pb^{2+} and Cd^{2+} ions followed the order: corn stalk xanthate > wheat stalk xanthate ≥ chitosan xanthate > starch xanthate. The results of kinetic modeling showed that the adsorption process was characterized by physical-chemical adsorption, and that a second-order kinetics equation described the adsorption process well. The optimum conditions for the adsorption of Cd^{2+} and Pb^{2+} by corn stalk xanthate were: adsorption time 2 hours, temperature 20–25 °C, and pH 6–8. The results serve as a reference for treating wastewater containing Cd^{2+} and $Pb2^+$.

Key words | adsorption characteristics, adsorption kinetics, biomass xanthate, cadmium, lead

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INTRODUCTION

Because of rapid industrialization and urbanization, heavy metal pollution in soil is becoming more serious due to the large amount of industrial waste produced and the extensive use of pesticides and fertilizers. Soil heavy metal contaminants tend to accumulate in plants, animals and humans through the food chain, posing a serious threat to the ecological environment and human health (Cobbina *et al.* 2015; Jorge 2017). Generally two methods are used to treat soil contaminated with heavy metals: passivating stabilization and leaching. Soil leaching is a kind of remediation technology for heavy metal contaminated sites; this technique is not sensitive to the degree of heavy metal pollution, and metals can be removed permanently with high efficiency. Because soil leaching is broadly applicable for the remediation of sites having medium and high concentrations of heavy metals, it is widely used (Farooq *et al.* 2010). At present, the most important technical problem associated with this technology is the treatment of waste leachate. Due to the lack of effective heavy metal treatment techniques for the contaminated leachates that are generated, the wider application of leaching technology to treat soils contaminated by heavy metals

is seriously restricted (Vijayaraghavan *et al.* 2009; Yao *et al.* 2016).

The commonly used means of treating waste liquid arising from leaching heavy metals from soil include precipitation, adsorption, ion exchange, electrochemical methods and biological methods, among others (Naushad *et al.* 2015a; Salman *et al.* 2015; Gaikar *et al.* 2016; Samadder *et al.* 2017). Among these, adsorption is most commonly used because it is highly efficient, requires less energy than other methods and offers a high level of environmental protection (Garg *et al.* 2007; Farooq *et al.* 2010; Rocha *et al.* 2015; Naushad *et al.* 2016a).

At present, many kinds of adsorption materials are commonly used, including active carbon, polymer/metal oxides, clays, polymers, and biopolymeric materials (Al-Othman *et al.* 2012; Pan *et al.* 2016; Alqadami *et al.* 2017b). Nevertheless, low cost, reliable, and efficient materials are still needed. Xanthate adsorptive materials (Tan *et al.* 2008; Magnacca *et al.* 2014) have been used successfully to adsorb heavy metals; they are obtained from raw materials such as starch, cellulose and chitosan. To prepare xanthate materials that are highly efficient, low cost and

environmentally friendly from a wide range of raw materials, much attention has been paid to the research and production of these materials (Babel & Kurniawan 2003; Zhou *et al.* 2011).

During the preparation of biomass xanthate, some hydroxyl groups on the macromolecules (e.g., cellulose, starch and chitosan) are replaced by xanthan groups. The xanthan groups increase the number of active groups in the raw materials, thereby increasing the number of sites where heavy metals can be captured; the strength with which metal ions are adsorbed also is increased. Biosorption of heavy metals by biomass xanthate occurs through a complex mechanism. In general, the concentration of heavy metals in water is small because they are insoluble. However, when biomass xanthate is added in the presence of heavy metal ions such as Cd^{2+}, Pb^{2+} and Cu^{2+}, a chelation reaction produces a stable chelate precipitate that has a small solubility product; thus, the heavy metal ions are immobilized on the xanthate and removed from the liquid (Zhou *et al.* 2009; Salam *et al.* 2011).

At present, research on the adsorption of heavy metal ions in wastewater by biomass xanthate is in the developmental stage at laboratory scale. Coconut sawdust xanthate prepared at room temperature was shown to have an adsorption efficiency of 99.4% for Pb^{2+} at room temperature (Yadav *et al.* 2013). The saturated adsorption capacity of xanthate for Cu^{2+} was 103.97 mg·g^{-1} (Ai *et al.* 2015). Zhang *et al.* (2016) prepared hydroxypropyl cellulose xanthate to treat wastewater containing Cu^{2+} and demonstrated the material had a saturated adsorption capacity of 126.58 mg·g^{-1}. Wang *et al.* (2017) used bagasse cellulose xanthate to treat wastewater containing Pb^{2+}, Cu^{2+} and Zn^{2+} ions, and demonstrated saturated adsorption capacities for the three heavy metals of 558.9 mg·g^{-1}, 446.2 mg·g^{-1}, and 363.3 mg·g^{-1}, respectively. Feng & Wen (2017) prepared cross-linked starch xanthate to treat wastewater containing Pb^{2+} and Cd^{2+}, and demonstrated saturated adsorption capacities of 47.11 mg·g^{-1} and 36.55 mg·g^{-1}, respectively.

The present study was undertaken because few studies have reported using xanthate materials to treat complex soil leachate containing Cd^{2+} and Pb^{2+}. The objectives of this study were to determine the relative adsorption effectiveness of four kinds of biomass xanthate in removing Cd^{2+} and Pb^{2+} contained in soil leachate and to quantify the effects of pH and temperature on the adsorption efficiency. The intention was to provide a reference and basis for the application of biomass xanthate to treat waste leachate from heavy-metal contaminated soil.

MATERIALS AND METHODS

Preparation of biomass xanthate

To obtain alkali wheat stalk and corn stalk, samples (10 g) of wheat stalk (cultivar 'Huaimai 28', Lianyungang, Jiangsu, China) or corn stalk (from Beijing Fangshan District) were added to 200 mL of 20% NaOH solution, stirred for 24 hours, filtered and washed three times with distilled water, then dried for 15 hours at 60 °C. At room temperature and atmospheric pressure the alkaline stalk was added to 200 mL of 10% NaOH solution and 10 mL CS_2 and allowed to stand for 3 hours at room temperature, after which 100 mL of 5% $MgSO_4$ solution was added. The mixture was then stirred for 30 min, after which excess CS_2 was removed by placing the mixture in a 70 °C constant temperature water bath for 30 min. Then, 1% diluted $MgSO_4$ and water were added sequentially to leach the sample at room temperature. The resulting corn stalk xanthate and wheat stalk xanthate were designated 'YCX' and 'XCX', respectively.

The chitosan xanthate (QCX) and starch xanthate (DCX) were prepared by the method reported in previous studies (Beyki *et al.* 2014; Ai *et al.* 2015).

Adsorption of lead and cadmium in wastewater by xanthate

Adsorption experiments were performed by separately placing each of the four different xanthate materials (0.20 g) in 1 L of a solution of simulated wastewater containing $CdCl_2$ and $PbNO_3$ (Pb^{2+} and Cd^{2+} concentrations of 100 mg·L^{-1} each). Each mixture was then placed in a 25 °C constant temperature water bath and stirred continuously using a magnetic stirrer. Samples (approximately 5 mL each) were withdrawn from each mixture at the beginning of the experiment (0 hour), and thereafter at 5, 10 20, and 40 min and 1, 2, 3, 4, 6, 8, 12, 24 and 36 hours. Samples were filtered through a 0.45 μm membrane and the resulting filtrates were analyzed using inductively coupled plasma optical emission spectrometry (ICP-OES, Optima 5300 DV, Perkin Elmer, Inc., Waltham, MA, USA) to determine the Cd^{2+} and Pb^{2+} concentrations (Wang *et al.* 2016b).

To determine the effects of external factors (pH and temperature) on the adsorption of Pb^{2+} and Cd^{2+} by biomass xanthate, the simulated wastewater was placed in a 100 mL plastic centrifuge tube with 0.20 g xanthate, and single-variable controlled experiments were conducted.

The samples were subjected to six different temperatures (25, 30, 35, 40, 45, and 50 °C), six different pH values (3, 5, 6, 7, 8, and 10) and seven different reaction times (5 min, 10 min, 20 min, 30 min, 1 hour, 2 hours, and 4 hours). Samples were oscillated during each reaction and then filtered. The clear filtrates were analyzed for Cd^{2+} and Pb^{2+} ion concentrations by ICP-OES.

zTo reveal the adsorption mechanism of Cd^{2+} and Pb^{2+} on YCX, Fourier transform infrared spectroscopy (FTIR) was used to examine the YCX before and after the adsorption of Cd^{2+} and Pb^{2+}. Dried samples were mixed with pure KBr in the proportion of 1:100 and ground into a fine powder. Then, the powder was pressed using a tablet-forming machine into a transparent sheet. The FTIR spectrum was produced by scanning in the range 400–4,000 cm^{-1}.

Statistical analysis

The adsorption amount and kinetic adsorption of Cd^{2+} and Pb^{2+} on the biomass xanthates were analyzed using Microsoft Excel 2013 (Microsoft Corp., Redmond, WA, USA).

Equation (1) (Bogue 1915) was used to calculate the adsorption capacity of biomass xanthate for Cd^{2+} and Pb^{2+}:

$$Q = (\rho 0 - \rho e)V/m \qquad (1)$$

in which Q is the ion adsorption amount, mg·g^{-1}; $\rho 0$ is the concentration of ions in solution before adsorption, mg·L^{-1}; ρe is the concentration of ions in solution after adsorption, mg·L^{-1}; V is the volume, L; and m is the quantity of xanthate, g.

The kinetic parameters of adsorption were used to characterize the chemical reaction rate and reaction mechanism (Langergren & Svenska 1898; Khaled & Amin 2009; Boparai *et al.* 2011; Ferreira *et al.* 2015; Arabi *et al.* 2017). Equation (2) represents a quasi-second order kinetic reaction:

$$\frac{dq}{dt} = k_2(q_e - q)^2 \qquad (2)$$

in which q is a unit adsorption amount of heavy metals (i.e., Cd^{2+} and Pb^{2+}) by the adsorbent material (xanthate) at t time, and q_e is the unit adsorption amount of heavy metals when adsorption equilibrium is reached. k_2 is a second-order kinetic adsorption rate constant, and t is the adsorption time (McKay *et al.* 1998).

The experimental data were analyzed using SPSS statistical software (IBM Corp., Armonk, NY, USA). Origin

8.6 data analysis and graphing software (OriginLab Corp., Northampton, MA, USA) was used to produce figures.

RESULTS AND DISCUSSION

Cadmium and lead adsorption properties of biomass xanthates

During the adsorption process, the adsorption amount usually increases as the contact time increases until the adsorbate reaches adsorption equilibrium. The unit adsorption capacity of the four xanthate materials for Cd^{2+} and Pb^{2+} under different adsorption times is shown in Figure 1. Each material exhibited periods of rapid and slow adsorption for both Cd^{2+} and Pb^{2+}. Between 0 and 1 hour, the Cd^{2+} and Pb^{2+} adsorption amount on each xanthate material increased rapidly. The adsorption rate gradually slowed between 1 and 2 hours, and adsorption equilibrium was gradually reached after 2 hours.
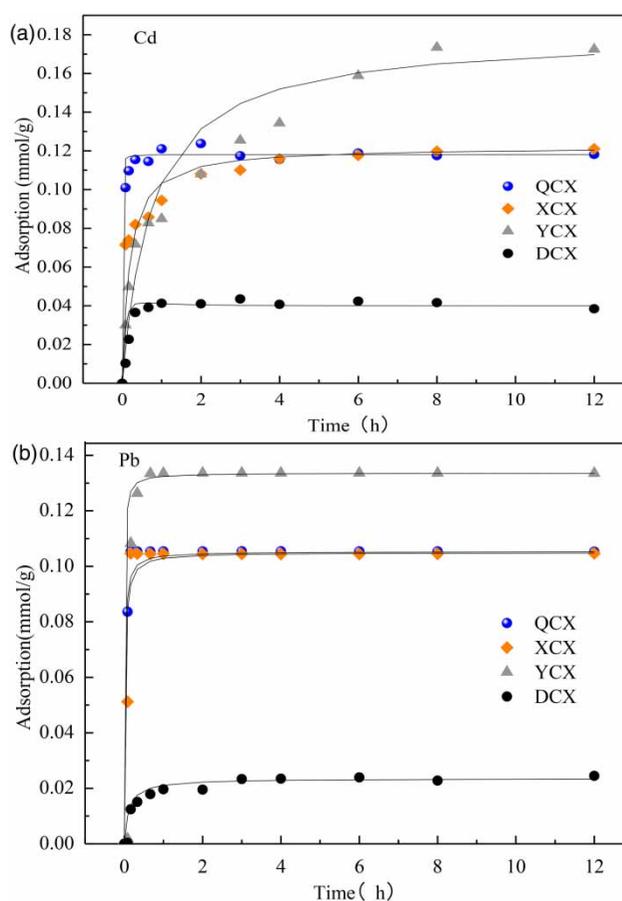

Figure 1 | Adsorption of (a) Cd^{2+} and (b) Pb^{2+} from simulated wastewater by chitosan xanthate (QCX), starch xanthate (DCX), corn stalk xanthate (YCX), and wheat stalk xanthate (XCX).

Nevertheless, the specific adsorption behaviors of the four xanthate materials differed. The adsorption of Cd^{2+} by QCX and DCX occurred rapidly in the period from 5 to 40 min, and after 40 min the adsorption quantity changed little (i.e., equilibrium was reached in approximately 40 min). In contrast, the adsorption of Cd^{2+} by XCX and YCX was slower within the period 5 min to 1 hour (adsorption quantities of 0.018 $mmol \cdot g^{-1}$ to 0.085 $mmol \cdot g^{-1}$, respectively) and the attainment of adsorption equilibrium took a longer time (8 hours). The rate of Pb^{2+} adsorption by all xanthate materials was rapid within 5 to 40 min, and adsorption equilibrium was reached after approximately 1 hour. The largest Pb^{2+} adsorption quantity was achieved by YCX; between 40 min and 1 hour, 0.121 $mmol \cdot g^{-1}$ was adsorbed, which increased to 0.133 $mmol \cdot g^{-1}$ at equilibrium (after 1 hour).

The experimental results showed that the adsorption capacity of the four xanthate materials was different for Cd^{2+} and Pb^{2+}, and followed the order YCX > QCX > XCX > DCX. As the best adsorbent, YCX exhibited an adsorption capacity for Cd^{2+} and Pb^{2+} of 0.170 $mmol \cdot g^{-1}$ and 0.133 $mmol \cdot g^{-1}$, respectively. The degree of substitution of xanthate groups, which plays a major role in the preparation process of the xanthate materials, determines the capacity of the materials to absorb heavy metals. The difference in adsorption capacity of the xanthate groups is also caused by differences in their characteristics. The relatively weak adsorption capacity of starch xanthate may be due to its low stability and a structure that deteriorates easily (Cauletti 1973). The preparation of chitosan xanthate produces a salt that has a large particle size, and the coordination reaction occurs on the surface, so that the overall adsorption capacity is not high. The difference in adsorption capacity between corn stalk and wheat stalk is due to a greater degree of lignification of wheat stalk. Although wheat stalk has a high cellulose content, it also has a high degree of crystallinity and the free area for adsorption is relatively small. Thus, the type of cellulose xanthate in wheat stalk has fewer adsorption sites. In contrast, the preparation process and corn stalk fiber groups are more likely to introduce xanthate molecules than wheat stalk; therefore, maize stalk has better heavy metal adsorption performance than wheat stalk (Wang *et al.* 2016b).

Among the four kinds of biomass xanthate, YCX was the most effective adsorbent of both Cd^{2+} and Pb^{2+}, in agreement with findings by Deng *et al.* (2012) and Wang *et al.* (2016b). Furthermore, for any given xanthate material, the adsorption of Pb^{2+} was more rapid than adsorption of Cd^{2+}. This result also was obtained in research by Deng

et al. (2012), who also showed that the adsorption and binding of Pb^{2+} to biomass xanthate was stronger than that of Cd^{2+}. Although the ion radius of Cd^{2+} is smaller than that of Pb^{2+}, the hydrated ion radius of Cd^{2+} is greater than the hydrated ion radius of Pb^{2+}, leading to a stronger adsorptive force between Pb^{2+} and an adsorbent (Jauhar & Rita 2016). At the same time, the solubility product of a xanthic acid group and Pb^{2+} to form salt is less than that of Cd^{2+} to form salt, and the affinity of Pb^{2+} to a xanthic acid group is greater than that of Cd^{2+}. Consequently, a coordination reaction occurs more easily with Pb^{2+} than with Cd^{2+}, and the adsorption rate is also faster (Deng *et al.* 2012).

Adsorption kinetics of cadmium and lead in simulated wastewater

The quasi-second order kinetic equation describes all the adsorption processes (including outer membrane diffusion, surface adsorption and particle diffusion) that can accurately reflect the adsorption mechanism of Cd^{2+} and Pb^{2+} on the biomass xanthates examined in this study. Thus, the quasi-second order equation was adopted to describe the kinetic data of Cd^{2+} and Pb^{2+} adsorption on the four xanthate materials. In portraying these data graphically (Figure 2), the abscissa is time (t in hours) and the ordinate is the quantity t/Qt ($mg \cdot h^{-1} \cdot mg^{-1}$). The best fit equations for each heavy metal and each xanthate material are also shown in Figure 2. The range of the correlation coefficient R^2 of equations describing Cd^{2+} adsorption was 0.989–0.9999, and the range of the correlation coefficient R^2 of equations describing Pb^{2+} adsorption was 0.9979–0.9999. The high R^2 values indicated that a quasi-second order kinetic equation described the Cd^{2+} and Pb^{2+} adsorption process involving the four biomass xanthate materials well. Furthermore, the form of the equation demonstrated that adsorption occurred via a physical-chemical composite process.

Effect of adsorption time on the adsorption of cadmium and lead by corn stalk xanthate

Figure 3(a) shows that as adsorption time increased, the amount of Cd^{2+} and Pb^{2+} adsorbed by YCX first increased rapidly, then slowed slightly, and finally achieved equilibrium. At the adsorption times of 1 hour and 2 hours, respectively, the unit adsorption amount of Cd^{2+} (0.091 $mmol \cdot g^{-1}$) and Pb^{2+} (0.067 $mmol \cdot g^{-1}$) by YCX reached the maximum. This occurred because there were abundant
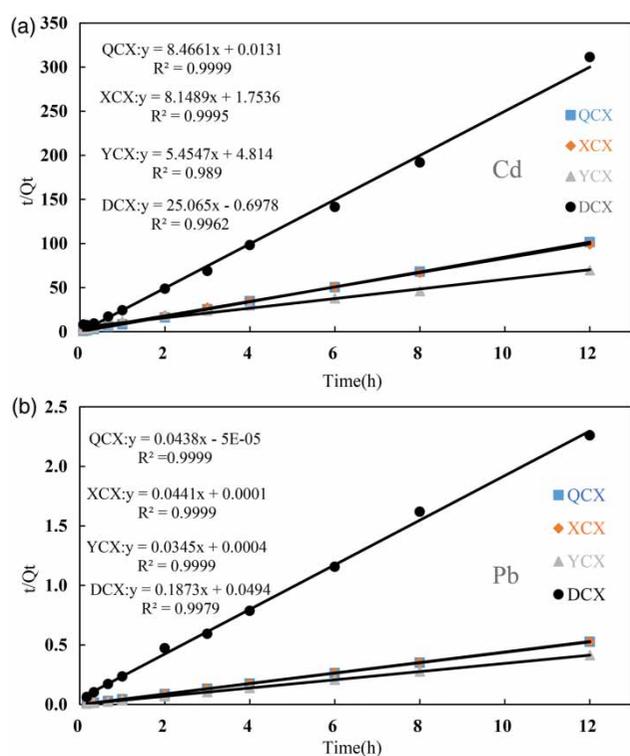
Figure 2 | Quasi-second order kinetic equations describing adsorption of (a) Cd^{2+} and (b) Pb^{2+} from simulated wastewater by chitosan xanthate (QCX), starch xanthate (DCX), corn stalk xanthate (YCX) and wheat stalk xanthate (XCX).

adsorption sites on the surface of YCX. The initial stage of adsorption mainly occurs at the surface interface (Simonin 2016), but as adsorption time increases, the adsorption gradually reaches a saturation state. This pattern is consistent with that described by the quasi-second order kinetic equations (described in the section 'Adsorption kinetics of cadmium and lead in simulated wastewater'). The adsorption of Cd^{2+} and Pb^{2+} on YCX occurs either by chemical adsorption or via shared electrons. After comprehensive comparison, the recommended adsorption time when using YCX in the treatment of Cd^{2+} and Pb^{2+} in wastewater was determined to be ≥ 2 hours.

Effect of adsorption temperature on the adsorption of cadmium and lead by corn stalk xanthate

Figure 3(b) shows that as the temperature increased from 25 °C to 50 °C, adsorption of Pb^{2+} by YCX first increased, then decreased, and increased slightly again to reach equilibrium at approximately 40 °C. The overall change in the adsorption of Pb^{2+} was modest (0.054–0.068 mmol·g^{-1}). However, in the same temperature range, the adsorption of Cd^{2+} gradually decreased (from 0.092 to 0.081 mmol·g^{-1})
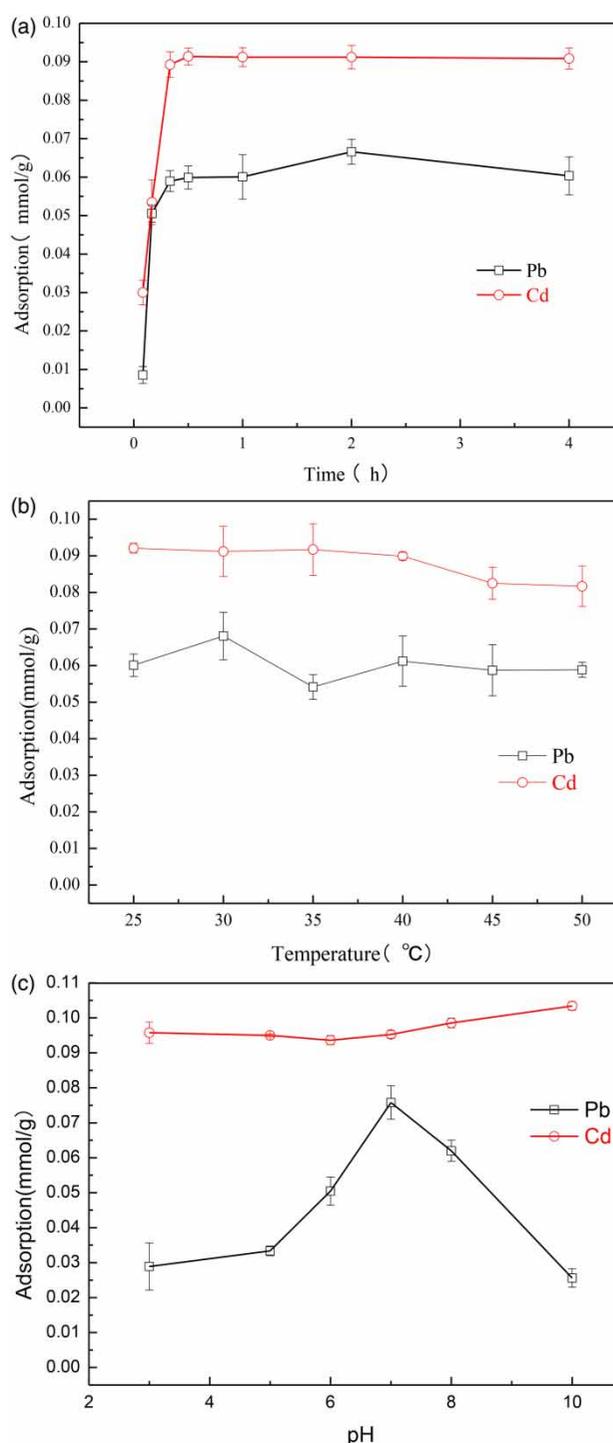

Figure 3 | Effects of (a) adsorption time, (b) temperature and (c) pH on the capacity of corn stalk xanthate to adsorb Cd^{2+} and Pb^{2+} from simulated wastewater.

as the temperature increased (Alqadami *et al.* 2017b). These results indicated that the overall optimum temperature for adsorption of Cd^{2+} and Pb^{2+} by YCX was 20–25 °C. Wang *et al.* (2017) studied the effect of temperature on the

adsorption of Pb^{2+} and Cu^{2+} by bagasse xanthate. They concluded that the mixing mechanism was dominant in the adsorption process and was mainly controlled by ion exchange and the complexation of cellulose xanthate with heavy metal ions. Because these results demonstrate that temperature has little influence on the adsorption of Cd^{2+} and Pb^{2+} by YCX, YCX will be relatively unaffected by seasonal temperature changes in the treatment of wastewater containing heavy metals. This stability is conducive to using YCX in practical applications.

Effect of pH on the adsorption of cadmium and lead by corn stalk xanthate

Solution acidity is an important factor affecting the migration and transformation of heavy metals in a liquid medium. Figure 3(c) shows that as the pH increased from low to high, the adsorption amount of Pb^{2+} first increased and then decreased, such that the maximum adsorption amount was at pH 7. Although some Pb^{2+} ions exist in the form of $Pb(OH)_2$ at pH 6, the ionic product of lead xanthate from corn stalk is much smaller than that of $Pb(OH)_2$. Therefore, the main reason for the decrease in Pb^{2+} concentration was its adsorption onto corn stalk xanthate. The adsorption of Cd^{2+} increased slightly (from 0.096 to 0.103 $mmol \cdot g^{-1}$) as the pH increased from 3 to 10. These results occurred because when the pH is low, a large amount of H^+ occupies the active sites on the xanthate adsorbent, reducing the opportunity for Cd^{2+} and Pb^{2+} to bind (Naushad *et al.* 2017). Furthermore, the electrostatic effect of H^+ at the interface also inhibits the approach of Cd^{2+} and Pb^{2+} ions. Therefore, the adsorption amount of the two metals is not high under highly acidic conditions. As the pH increases, a larger number of active sites become available to facilitate adsorption of Cd^{2+} and Pb^{2+}.

In summary, the optimal pH for using YCX to treat wastewater containing Cd^{2+} and Pb^{2+} was in the range 6–8. Therefore, in practice, YCX can be combined with limewater treatment of wastewater containing high concentrations of Cd^{2+} and Pb^{2+}.

Fourier transform infrared spectrometry characterization of corn stalk xanthate before and after adsorption of cadmium and lead

The changes of different functional groups in YCX as a result of Cd^{2+} and Pb^{2+} adsorption were qualitatively analyzed by FTIR. Wang *et al.* (2016a) studied the structural changes in different xanthates after Cu^{2+} adsorption.
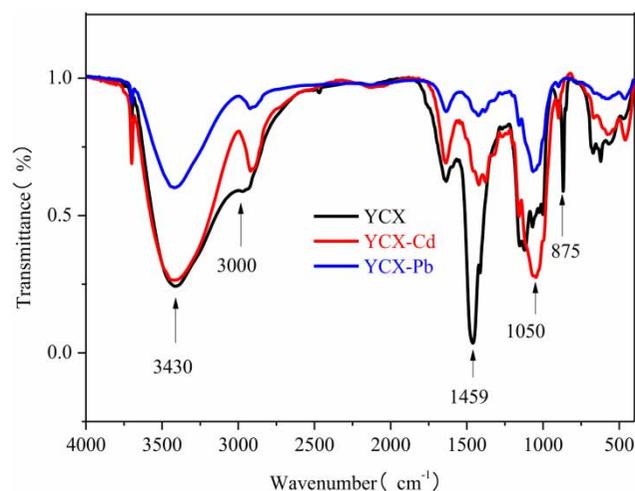

Figure 4 | Fourier transform infrared spectra of corn stalk xanthate before (YCX) and after adsorbing Cd^{2+} (YCX-Cd) and Pb^{2+} (YCX-Pb).

Figure 4 shows that compared with the pre-adsorption peaks in YCX at $3,000\ cm^{-1}$ and $1,459\ cm^{-1}$, the absorption peak strength increased following adsorption of Cd^{2+} and Pb^{2+}; the band at $1,459\ cm^{-1}$ was due to CH_2 bending mode (Naushad *et al.* 2016b). The change of characteristic peaks at $1,050\ cm^{-1}$ were attributed to the ether groups of the YCX, indicating that the reaction generated unsaturated bonds and C-OH. Similarly, the corresponding adsorption trough at $1,459\ cm^{-1}$ was significantly weakened by the adsorption process, indicating that this was the deformation vibration of C-S in YCX. The original YCX coordinate reaction occurred, resulting in YCX-Cd. The spectral peak at $3,430\ cm^{-1}$ in YCX-Pb obviously decreased in intensity, illustrating that -OH was also involved in the reaction (Ai *et al.* 2015; Zeng *et al.* 2015; Wang *et al.* 2016a; Alqadami *et al.* 2017a; Dil *et al.* 2017).

Adsorption experiment using corn stalk xanthate to treat wastewater containing cadmium and lead

The results of using corn stalk xanthate to treat simulated wastewater containing Cd^{2+} and Pb^{2+} are shown in

Table 1 | Effect of corn stalk xanthate on lead and cadmium concentrations in simulated wastewater

Element	Pb	Cd
Initial concentration ($mg \cdot L^{-1}$)	18.89	0.24
Concentration after adsorption ($mg \cdot L^{-1}$)	0.15	0.04
Removal efficiency (%)	99.21	83.30

Table 2 | Comparison of adsorption capacities for Pb^{2+} removal

Adsorbents	Adsorbent dosage (g/mL)	pH	T (K)	Initial concentration of Pb^{2+} (mg L^{-1})	Removal of Pb^{2+} (%)	Initial concentration of Cd^{2+} (mg L^{-1})	Removal of Cd^{2+} (%)	References
YCX	0.4/100	6	298	18.89	99.21	0.24	83.30	Present study
Sodium dodecyl sulfate acrylamide Zr(IV) selenite	0.5/20	6	298	10	90.5	~	~	Naushad (2014)
MWCNTs/ThO$_2$	0.02/100	5	318	5	95.5	~	~	Mittal *et al.* (2016)
Ti(IV) iodovanadate cation exchanger	0.1/50	6	298	20	94.8	~	~	Naushad *et al.* (2015b)
EDTA-Zr(IV)	0.4/40	6	298	20	91			Naushad *et al.* (2015c)
Polyaniline Sn(IV) tungstomolybdate nanocomposite	0.3/30	6	298	20	88			Bushra *et al.* (2015)
Ash	0.01/100	6	298	25	98			Ghasemi *et al.* (2014a)
Fe nanoparticles loaded ash	0.01/100	6	298	25	99			Ghasemi *et al.* (2014a)
Sawdust activated carbon	0.05/30	4	298	100	96			Ghasemi *et al.* (2014b)
Polyaniline Sn(IV) silicate	0.2/20	9	298			200	92	Naushad (2013)
Curcumin formaldehyde resin	0.1/50	7	298			100	91.2	Naushad *et al.* (2015d)

Table 1. The Cd^{2+} and Pb^{2+} removal efficiencies were 99.21% and 83.3%, respectively.

The adsorption capacities of YCX for the removal of Cd^{2+} and Pb^{2+} were compared with those of other adsorbents reported in the literature and the values are shown in Table 2. It is clear from Table 2 that the adsorption capacities of YCX were comparable with those of other materials. These results illustrate that corn stalk xanthate is a promising adsorbent for removing Cd^{2+} and Pb^{2+} from wastewater.

CONCLUSIONS

This laboratory study determined the effectiveness of biomass xanthates made from starch, chitosan, wheat stalk, and corn stalk in adsorbing Cd^{2+} and Pb^{2+} (100 mg·L^{-1}, each) from simulated wastewater. The results justify the following conclusions.

The Pb^{2+} and Cd^{2+} adsorption efficiency of corn stalk xanthate is superior to that of the other xanthates (corn stalk xanthate > wheat stalk xanthate ≥ chitosan xanthate > starch xanthate). The adsorption of Pb^{2+} and Cd^{2+} on biomass xanthates occurs by physical-chemical adsorption and is accurately described by quasi-second order kinetics. The optimum conditions for the adsorption of Pb^{2+} and Cd^{2+} by corn stalk xanthate are adsorption time, 2 hours; temperature, 20–25 °C; and pH, 6–8.

ACKNOWLEDGEMENTS

DECLARATIONS OF INTEREST

None.

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