

Selective removal and recovery of Fe(III) by garlic residue gel adsorption

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Abstract: Removal of iron in hydrometallurgical processes is a quite popular challenge, and the traditional methods such as precipitation may cause severe secondary pollution and resources waste. In present study, we attempted a cheap and effective technique to remove the iron ions by adsorption onto garlic residue gels. A simple chemical modification method to modify the peel by calcium hydroxide was proposed. Results showed that the optimal equilibrium pH is about 2.5 for 90 % adsorption without the hydrolysis of Fe(III). Adsorption equilibrium was attained within 60 min. The adsorption process can be described well by Langmuir model and pseudo-second-order kinetic equation, respectively. The maximum adsorption capacity for Fe(III) ions was found to be 1.4 mol/kg. The sulfenic acid, pectic acid, polyphenolic and alliin components contained in the garlic peel are inferred to be the main ligands responsible for the uptake of Fe(III) ions onto the gel. The simulated solutions referring to the hydrometallurgical process of nickel and copper were prepared to test the selective removal behavior of Fe(III), and the possibility of recovery and reuse of the adsorbed iron was also discussed. The present work may help to recycle and reuse the huge amount of iron resources in the real hydrometallurgical processes, and also bring a more ecofriendly, cleaner and shortened process for many traditional hydrometallurgical processes.

25 **Key words:** Iron adsorption; Garlic wastes; Hydrometallurgy; Pollution abatement; Zero-valent iron

0 Introduction

Iron is an abundant element on the earth's crust, and it is the main component of more than 300 600 minerals^[1], therefore the separation of iron is a quite popular issue for many nonferrous metallurgical processes, such as the metallurgical processes of zinc, manganese, copper, nickel, cobalt, etc. The separation technologies of iron promote the development and application of hydrometallurgy. Removal of iron from the aqueous solution by precipitation is quite popular due to its simpleness and effectiveness. The most typical one is precipitated as jarosite, which is usually used in the zinc hydrometallurgical process, while its sludge is quite difficult to be treated though it contains quite a few valuable elements such as zinc, silver and copper. The similar problem occurs to the goethite and hematite precipitation process. So it is quite necessary to develop more effective and efficient techniques to remove the iron. Ion exchange and solvent extraction have ever been attempted^[2], and it was found that the elution or stripping of Fe(III) is quite difficult due to the very strong affinity to the functional groups between the Fe(III) and IX and SX materials, and furthermore it was easy to hydrolysis for Fe(III) causing precipitation and fouling in the micropores of resins or emulsification of organic extractants, so IX and SX were seldom applied in the real industrial practice. In recent years, biosorption has become the concern in the separation of metal ions due to its cheapness and effectiveness^[3-11]. While how to get abundant biowastes, how to transfer biowastes into biosorbents in a simple and effective way, and how to use it in the real process, it is the focus questions that should be solved for any biosorbents.

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Based on above three principles for the application of biosorbent, in this study, we choose the garlic waste as the raw material for the preparation of biosorbent and used for the removal and recovery of iron from aqueous solution.

50 Typically, garlic peel (GP) is abundant in garlic industries and usually treated as wastes. Garlic peels were found to contain 11 to 12% pectin substances^[12], as well as other compounds of sulfenic acid, polyphenolic acid and alliin, which may make the garlic peel as a good candidate for the metal ions adsorption just by some simple chemical modification processes due to the original functional groups contained in the garlic wastes such as pectic -COOH and polyphenolic
55 -OH. Especially in China, it has been statistically found that at least three-quarters of the world's garlic was produced in China^[13-16]. So due to the high consumption of garlic, massive amounts of peels and the other wastes are disposed, without being used in a high-value way in the community. In this study, we propose that this agricultural waste can be used as a low-cost adsorbent to remove Fe(III) from aqueous solution. The biosorbent made by garlic peel has been investigated
60 for the removal of methylene blue^[17] and fluoride^[18], cadmium, heavy metal ions^[19], and gold^[20]. So in this work, we will try to evaluate the potentiality of garlic peel (GP) for the removal of Fe(III) from aqueous solution including the effect of initial concentration, contact time, solution pH and so on, and explore the further application of Fe-loaded garlic peel by some suitable post-treatment.

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1 Experimental

1.1 Chemicals

All chemical used in this study were of analytical purity, and purchased from National Chem. Ltd. China without further purification. 0.1M HCl and 0.1M NaOH were used to adjust the pH
70 value of experimental solutions. Deionized water used to prepare all the solutions.

1.2 Preparation of garlic peel adsorbent

The garlic peel was used as the raw material for the preparation of the chemically modified adsorbent, which was collected from Jinxiang county, Shandong province of East China. Chemical modification became popular and many researchers devised elaborate modification procedures^[21].
75 In our research, the garlic peel particles was modified with Ca(OH)₂ solution for 24h to improve the capacity of metal uptake. Calcium hydroxide not only facilitates the saponification for the activation of various functional groups, but also enables to remove water soluble components and bad smells in the garlic peel^[22]. In order to promote the saponification, a small amount of sodium hydroxide was added to keep the solution pH above 12 during the whole modification process.
80 After repeated decantation and filtration, modified garlic peel was washed with distilled water until neutral pH, and dried at 60°C inside a convection oven for 24h. The garlic peel was then crushed and sieved to obtain an average particle size controlled to 100-200µm. The final product of chemical modified garlic peel, designated as CMGP, is used for the following adsorption tests.

1.3 Instruments used for samples characterization

FT-IR spectroscopy was used to identify the chemical groups present in the adsorbents. Spectra of the adsorbent before and after Fe(III) binding were recorded in the wavenumber range of 400-4000cm⁻¹ using a JASCO-410 model FTIR spectrometer with the samples prepared as KBr

discs.

90 A pH meter (PHS-3C, Leici, China) was used to measure pH value of the suspension. The meter was standardized using buffer solutions with following pH values: 4.00, 6.86 and 9.00.

Shimazu atomic absorption spectrometer operating with an air-acetylene flame was used to analysis the concentration of iron. Three standard solutions in the liner range of the instrument were used to construct each calibration curve. Samples reading beyond the liner range of the
95 references were diluted to appropriate concentrations. All the required experimental solutions were diluted with 0.1 M hydrochloric acid before analysis by atomic absorption spectrophotometer (Shimazu AAS-6800, Japan).

An air bath shaker of (BS-1E, made in China) was used for all the adsorption experiments. Shaking speed can be adjusted. After a period of time for adsorption, the used adsorbents were
100 filtrated by filter paper, and if the filtrates were diluted to appropriate concentrations for detection. After dilution, a drop of 0.1M HCl was added in order to prevent Fe(III) hydrolysis.

A vacuum tube furnace(GSL-1500X-OTF, made in China) was used for the heat treatment of the Fe(III)-loaded gel.

1.4 Batch adsorption experiment

105 Adsorption experiments were conducted by mixing adsorbent with 15 mL Fe (III) ions solutions of desired concentrations in a 50 mL sealed conical flask using shaking thermostat machine at a set speed. Then conical flasks were then removed from the shaker, and final concentrations of Fe(III) in the solution was measured by Shimadzu model AAS-6800 atomic
110 absorption spectrophotometer. The amount of Fe(III) ions adsorption was calculated according to the following equation:

$$Q = \frac{(C_i - C_e)V}{W}$$
$$A = \frac{(C_i - C_e)}{C_i} \times 100\%$$

115 where A is the adsorption percentage of metal ions on the gel (%), Q denotes the amount of metal ion adsorbed per unit mass of the adsorbent (mol/kg^{-1}), V is the solution volume (dm^3), W is the dry mass of the adsorbent (kg), and C_i and C_e represent the metal ion concentrations in the solution before and after adsorption (mol/dm^3), respectively.

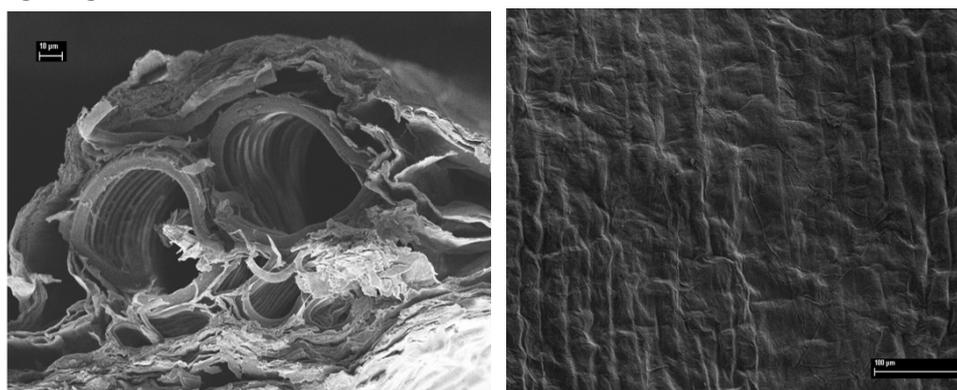
1.5 Elution test

120 To check the possibility of repeating use of CMGP, adsorption and elution experiments for Fe(III) were conducted. Twenty-five milligram CMGP was shaken with 15ml 100ppm Fe(III) solution at 298K for 1 h, then the mixture was filtrated and the residue gel was washed by distilled water three times. The metal ion-loaded gel was then shaken with 25ml 0.5 M hydrochloric acid in a conical flask at 293K for 2h. Above adsorption and elution experiments were repeated, and the
125 metal ion concentrations before and after adsorption was measured each time to evaluate the adsorption efficiency.

2 Materials and Methods

2.1 Adsorbent characterization

130 Fig.1 shows the SEM photo of chemical modified garlic peel. It is clear that the surface morphology of the gel is rough which is favorable for metal ions to be trapped and adsorbed on the gel. It also looks not so compact, which will be helpful for metal ions to diffuse or penetrate into the inner parts of the adsorbent particles and good for the fast adsorption [23]. It is also shown that the microstructure of the garlic peel has the characteristic of oriented growth, which is probable the components of cellulose that makes the garlic peel gel very durable for the adsorption and desorption processes.



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Fig. 1 SEM picture of CMGP gel

2.2 Effect of solution pH

The pH of the solution is an important factor in determining the ratio of surface reactions. The variation in adsorption capacity is largely due to the influence of pH on the surface adsorption behavior of CMGP gel.

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Effect of solution pH was studied at pH 1-5, as shown in Fig.2, it can be found that with the pH increasing, the adsorption percentage of Fe(III) also increases. Taking into account of that Fe(III) is easy to precipitate when pH value is above 3.5 at the initial concentration of Fe(III) [24], it can be deduced that the contribution due to adsorption occurs mainly at pH below 3.5 and above this pH, the removal of Fe(III) was due to the hydrolysis and precipitation [25-27]. So in the real application, in order to avoid the coprecipitation of other co-existing ions caused by the precipitated Fe(OH)₃, selective adsorption can only occur in the pH range below 3.5 for Fe(III) at its low concentration of about several and several ten ppm, otherwise the obtained product was not the pure iron ions and difficult to remove the objective metal ions exactly. Ascribed to the above consideration, the optimum adsorption pH value is recommended to be about 3.0, at which the adsorption efficiency can be achieved approximately 80%.

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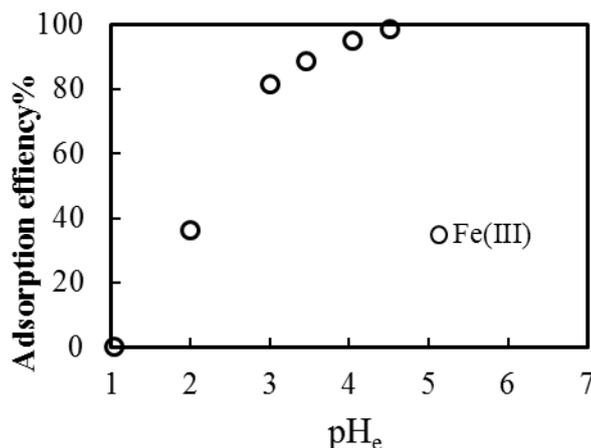


Fig. 2 Effect of equilibrium pH on adsorption of Fe(III) on garlic peel gel (Weight of gel = 25 mg, initial concentration of Fe(III) = 50 ppm, solution volume =15 ml, Time=120 min, Temp = 298 K, shaking rate = 180 rpm)

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2.3 Effect of coexisting ions

Fig.3 shows the adsorption efficiency of Fe(III) under the effect of coexisting ions namely Ni(II) and Cu(II) at different adsorbent amounts. It can be seen that the effect of Ni(II) and Cu(II) on the Fe(III)'s adsorption efficiency is negligible, due to the high selective adsorption for Fe(III) over the other two ions. So it can be deduced that in the hydrometallurgical processes of these two metals, the selective removal of iron is able to be anticipated.

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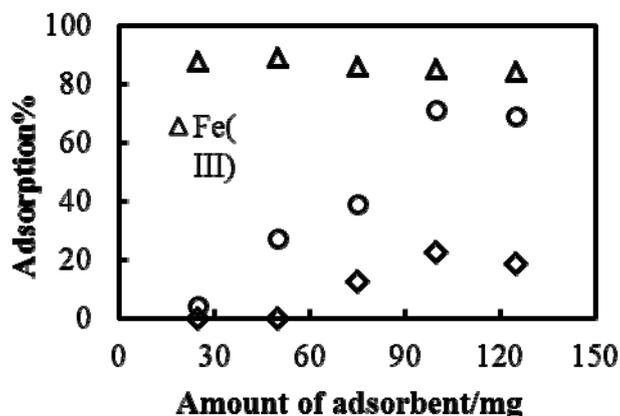


Fig. 3 Effect of adsorbent dose on the adsorption of Fe(III) coexist with different metal ions on CMGP gel. (Volume of solution=15 ml, initial concentration of Fe(III) = 50 ppm, initial concentration of Cu(II) = 50 ppm, initial concentration of Ni(II) = 50ppm, pH_i = 2.45, contact time = 3 h)

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2.4 Adsorption isotherm

Fig.4 shows the adsorption amount of Fe(III) when the initial concentration of Fe(III) varies between 2 and 10 mM at different pH values. Because of the easy hydrolysis trend of Fe(III) at higher pH as mentioned above, the maximum adsorption pH value in this experiment is set to 3.0.

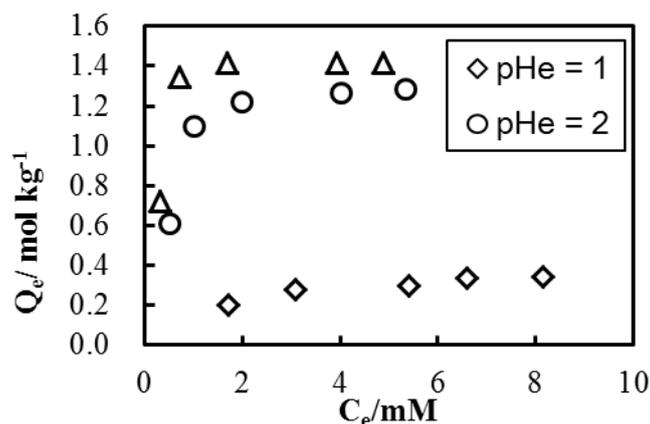


Fig. 4 Plot of adsorption isotherm for iron(III) ions on garlic peel gel (Weight of gel = 25 mg, solution volume = 15 ml, contact time=120 min, Temp = 298 K, shaking rate = 180 rpm)

Higher initial concentrations of iron ions give rise to the large loading capacity for iron ions, and to a certain concentration, the adsorption amount will tend towards equilibrium.

The Langmuir isotherm was used to describe above sorption phenomena. The Langmuir model is based on the assumption that a maximum adsorption corresponds to a saturated monolayer of solute molecules on the adsorbent surface, that the energy of adsorption is constant, and there is no transmigration of adsorbate in the surface [28-30].

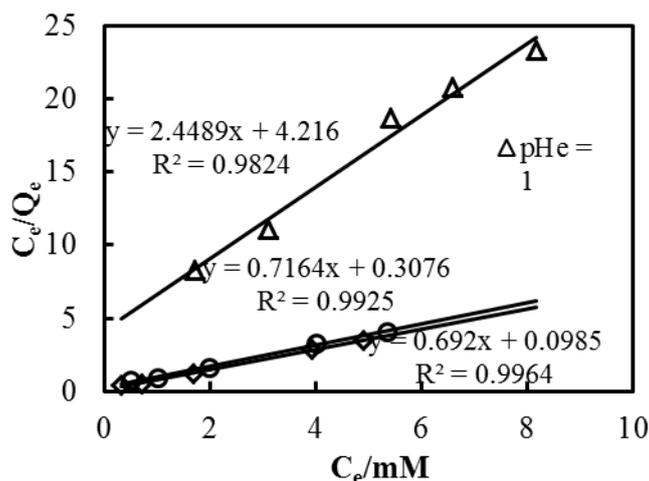
For a single solute, it is given by

$$q_e = q_m k_L C_e / (1 + k_L C_e)$$

And the linear form of the equation can be written as

$$\frac{C_e}{q_e} = \frac{1}{k_L q_m} + \frac{C_e}{q_m}$$

Where q_e is amount of heavy metal ions adsorbed per unit mass of adsorbent (mg/g) at equilibrium liquid phase concentration of heavy metal ion(mg/L). q_m and K_L are Langmuir constants indicating adsorption capacity and energy, respectively. The plots of c_e/q_e versus c_e at different temperatures were found to be linear, which indicates the applicability of the Langmuir model. The statistical significance of the correlation coefficient (R^2) for c_e/q_e versus c_e was the criteria by which the fitting of the data to Langmuir isotherm was tested. It demonstrates monolayer coverage of adsorbate at the outer surface of the adsorbent. The parameters q_m and K_L have been calculated and the results are represented in Fig.5. It shows that the adsorption of Fe(III) onto CMGP gel is a monolayer type that does not fully cover the surface of the CMGP gel. As seen from Fig.5, Langmuir isotherm fits well with the experimental data. This may be due to homogenous distribution of active sites on the CMGP gel surface, since the Langmuir equation assumes that the surface is homogenous [31]. Based on this model, the maximum adsorption capacity for the adsorption of Fe(III) onto the CMGP gel is found to be 1.44 mol/kg at pH 3.0, as a contrast, the corresponding values at pH 2 and 1 were also tested to be 1.40mol/kg and 0.41mol/kg, respectively. So it can be found that pH has quite great effect on the maximum adsorption capacity of Fe(III) onto the garlic peel gel, and large amount of protons will inhibit the adsorption of cations of Fe(III) on the gel [32].



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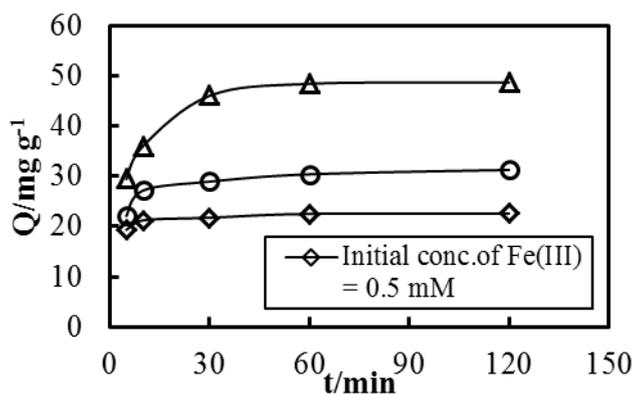
Fig. 5 Langmuir isotherms for Fe(III) adsorption onto CMGP gel at different Fe(III) initial concentrations(Weight of gel = 25 mg, solution volume = 15 ml, Temp = 298 K, shaking rate = 180 rpm)

2.5 Adsorption kinetics

Effect of contact time was studied at 5 min, 10 min, 30min, 60 min, 120min, respectively. Twenty-five milligram of CMGP dry gel was fed in each 15mL volume of Fe(III) ion solution having initial concentration of 0.5 mM, 1.0 mM, 2.0 mM at pH 3.0. Fig.5 shows the results of the adsorption equilibrium of Fe(III) ions on CMGP gel against time.

It can be observed that the adsorption amount of Fe(III) by CMGP gel adsorption increases with increasing contact time, and the adsorption equilibrium can be attained within 30 min, as shown in Fig.6, which is so short that makes the adsorption process be fast to finish in the real application. The adsorption amount is found to be 20, 30, 50 mg/g at initial concentrations 0.5, 1.0, 2.0 mM for Fe(III), respectively. Such adsorption behavior can be ascribed to the strong affinity of Fe(III) to the functional groups such as -COOH and polyphenolic -OH on the surface of the biosorbent particles, obviously this adsorption is a cation exchange process^[33-34].

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Fig. 6 Plot of adsorption amount vs. contact time for iron(III) ions on the CMGP gel(Weight of gel = 25 mg, solution volume = 15 ml, equilibrium pH = 3.0, Temp. = 298 K, shaking rate = 180 rpm)

It is clear that the Fe(III) adsorption amount increased with increasing Fe(III) concentration. With increasing Fe(III) concentration, more Fe(III) would be in the vicinity of CMGP gel, and the CMGP active sites would be well occupied, hence the adsorption amount of Fe(III) would increase correspondingly.

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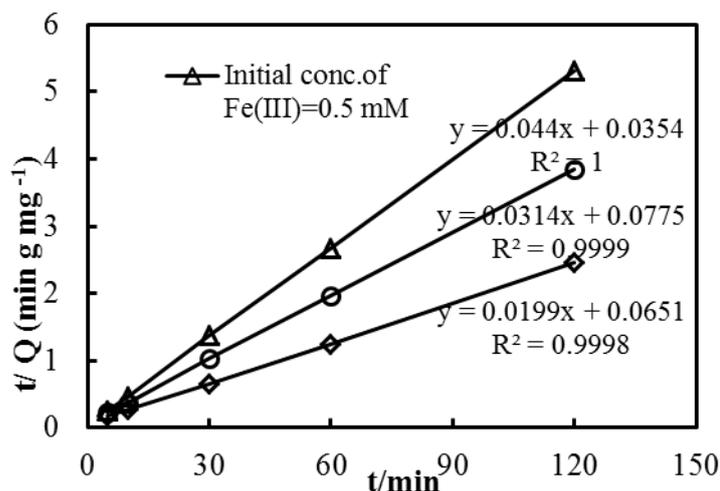
The adsorption kinetics of Fe(III) on CMGP gel was analyzed and found to be described by

applying pseudo-second-order model, which assumes that the rate is proportional to de aquare of the number of remaining free surface active functional group sites. This model can be written as follows^[35]:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e}$$

Where $K_2(\text{g}/(\text{mg}\cdot\text{min}))$ is constant of pseudo-second-order rate. The relationship between t/q_t and t is linear with a slope of $1/q_e$ and an intercept of $1/(K_2 q_e^2)$.

Fig.7 shows the application of pseudo-second-order model for the experimental data in Fig.6. As shown in Fig.7, the pseudo-second-order model fitting well the adsorption curves at different initial concentrations, and the theoretical values of q_e also agree very well with the experimental values as well as the theoretical values estimated by Langmuir model, which indicates that the adsorption conforms to the pseudo-second-order model well and may be used to explore the deep mechanism of adsorption kinetics^[36].



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Fig. 7 Pseudo-second-order kinetics for adsorption of Fe(III) adsorption onto CMGP gel (Weight of gel = 25 mg, solution volume = 15 ml, contact time=120 min, Temp. = 298 K, shaking rate = 180 rpm)

2.6 Adsorption kinetics

The FTIR spectra of CMGP gel before and after Fe(III) adsorption are shown in Fig.8. The adsorption peaks at 3426.47 cm^{-1} can be attributed to the O-H stretching vibrations of cellulose, absorbent water, or hemicelluloses. As shown in Table 1, The peaks at 1630.34 cm^{-1} and 1428.38 cm^{-1} corresponds to the asymmetric and symmetric stretching vibration of C=O bond in ionic carboxylic groups of $-\text{COO}-$, which may be assigned to the functional groups from the uslfenic acid, pectic acid, polyphenolic and alliin acid, which will be detailed discussed in the latter section.

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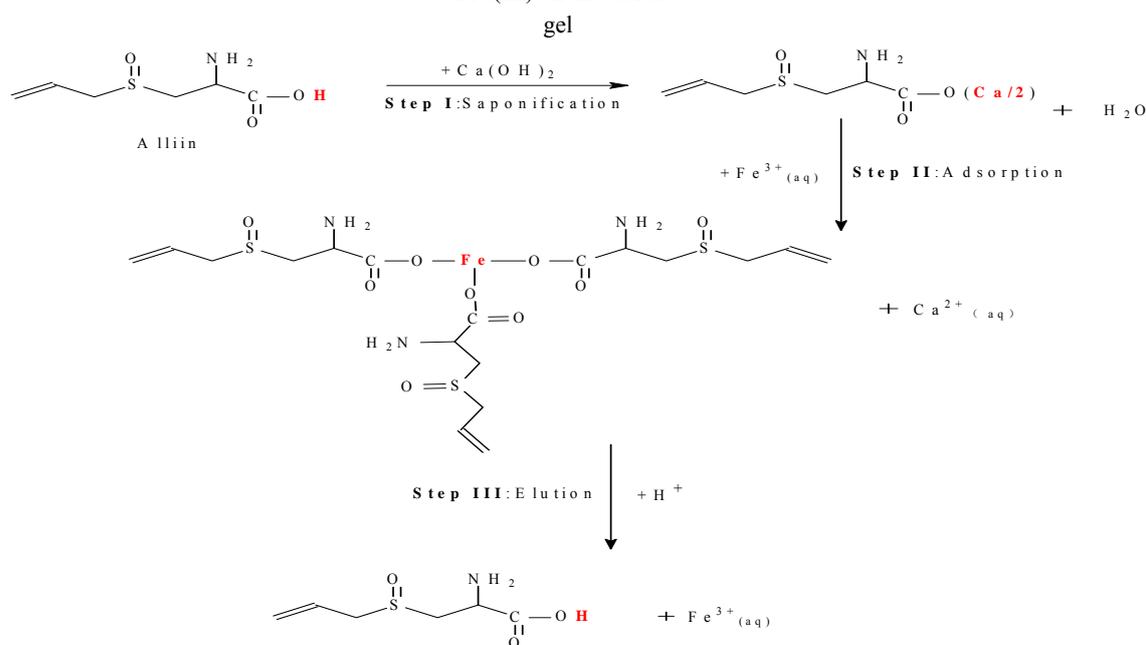
The adsorption mechanism of CMGP may include electrostatic attraction, ion exchange and surface complexation. It can be seen that after Fe(III) adsorption, -OH stretching vibration is shifted to 3424.33 cm^{-1} , the shift of this specific peak towards the lower wavenumber range after

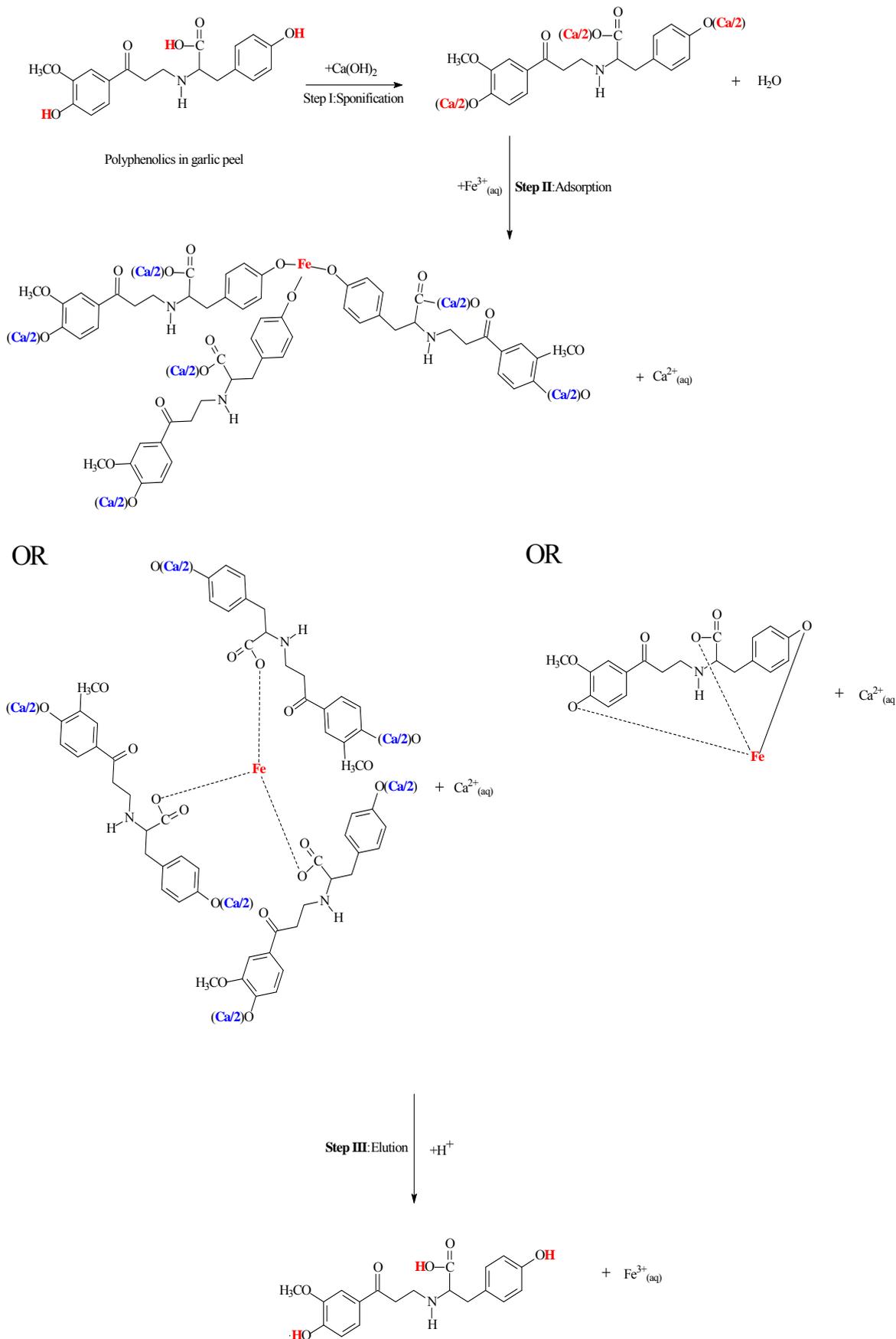
the iron ions adsorption suggested that chemical interactions between the iron ions and hydroxyl groups(-OH) occur on the biomass surface. Besides, -COOH stretching vibration is shifted to 1623.62 cm^{-1} and 1413.58 cm^{-1} , the shift of this specific peak towards the lower wavenumber range after the iron ions adsorption suggested that chemical interactions between the iron ions and carboxyl groups (-COOH) occur on the biomass surface. These results indicate that the functional groups mentioned above are mainly involved in the adsorption of Fe(III) onto the biomass^[37].
 Anyway, by comparing the two IR curves of CMGP gel and Fe(III)-loaded CMGP gel, it can be obviously found that after adsorption of Fe(III) ions, several peaks have become drastically weak, which confirms the chemical adsorption of Fe(III) ions onto the CMGP gel due to the formation of coordinated bonds between the metal ions and functional groups of gel.

Based on above analysis results, and by referring to the relative literature, we found that the acidic functional groups such as -COOH and polyphenolic -OH were probably the main role that contributes to the adsorption of metal ions onto the garlic peel gel^[38], and actually in our experimental study we found that the pH of the leaching solution of the crushed raw garlic peel particles will decrease drastically which shows the obvious acidic. So based on the comprehensive information, we deduced the principal mechanisms of the chemical modification of garlic peel and the Fe(III) adsorption and desorption process on the CMGP gel, as shown in Scheme I, in which chemical modification is more like a neutralization process between the biomass acid in the garlic peel and the added calcium hydroxide, and the adsorption and desorption (elution) processes are the typical cation exchange.

In addition, the high adsorption of Fe(III) on the CMGP may also be ascribed to the co-precipitation of adsorbed Fe(III) with calcium ions at high pH together with the cation exchange mechanism. Pectic substance such as acids in the biomass can also adsorb Fe(III) from solution.

Scheme 1 Illustration of modification of garlic peel, and the adsorption and elution of Fe(III) on the CMGP gel





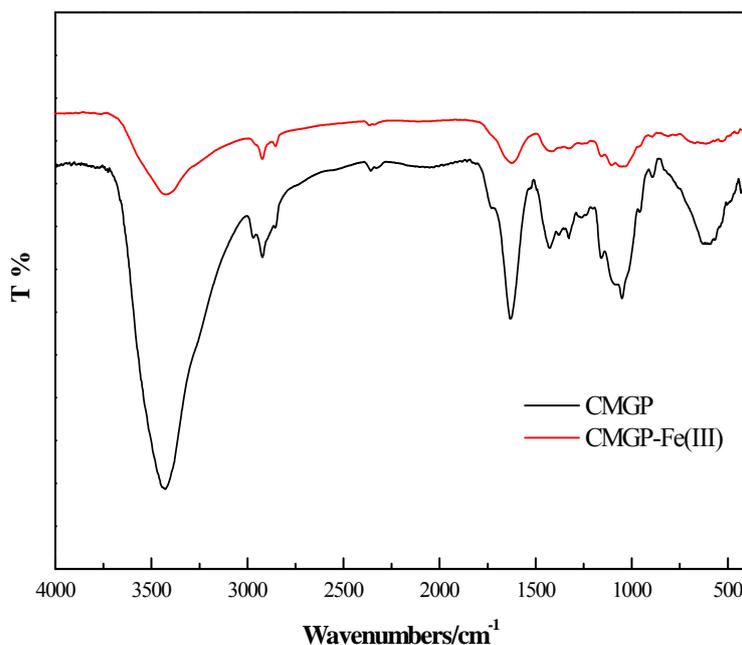


Fig. 8 FTIR curves of the chemically modified garlic peel before and after adsorption of Fe(III) ion

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Tab. 1 Characteristic peaks of functional groups by FTIR

Functional groups	Before adsorption/cm ⁻¹	After adsorption/cm ⁻¹
-OH	3426.47	3424.33
-CH	2922.26	2922.60
	2856.11	2854.08
	1630.34	1623.62
-COOH	1428.38	1413.58

2.7 Post-treatment of the Fe(III)-loaded adsorbent

Regeneration and reuse of the CMGP gel is crucial to practical application and environmental protection. The experimental results demonstrated that by using 0.5M hydrochloric acid as the elution solvent, as shown in Fig.9, the adsorption efficiency of Fe(III) were still remained more than 80% after nine cycles of adsorption-elution tests, indicating that the good possibility of its repeating usability.

It can be seen that the adsorption efficiency increased with increasing cycle times, that may show that the process of Fe(III) adsorption is also a process of modification process on garlic peels by Fe(III), probably in which the elution made the main contribution to the improvement of loading capacity.

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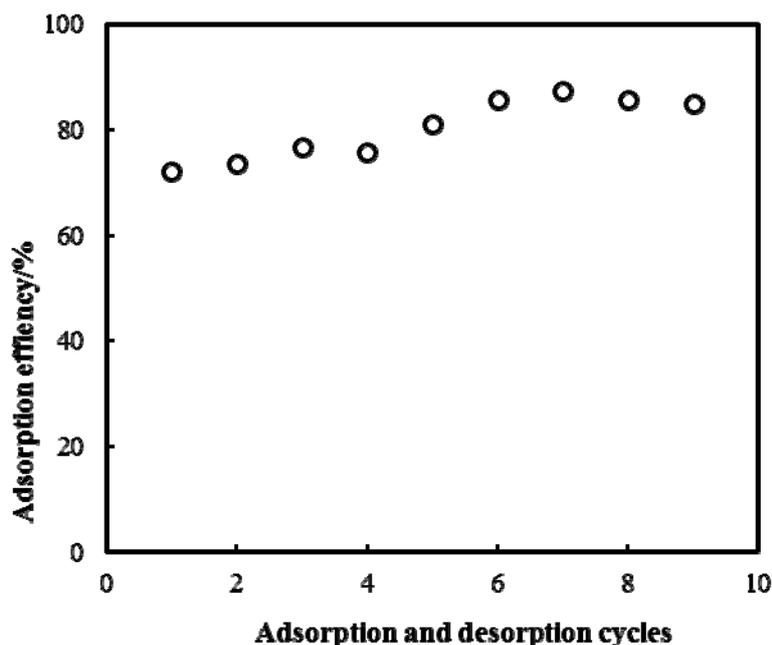


Fig. 9 The effect of cycle number for adsorption of Fe(III) adsorption onto GP (Weight of gel = 25 mg, solution volume = 15 ml, initial concentration of Fe(III) = 100ppm, contact time = 60 min, Temp. = 298 K, shaking rate = 180 rpm)

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After more than ten cycles of adsorption and elution, the used CMGP adsorbent will finally lose its adsorption capacity gradually. Here we put forward a good idea to produce fine iron powder by using galic peel biomass as the reducing agent due to its richment in hydrocarbons and so by combustion the Fe(III)-loaded gel in a protection atmosphere can be transferred to iron metal powder, which may find the new application in the water treatment such as the iron source for Fenton reaction in the waste water purification. Fig.10 presents the TG/DSC curves of Fe(III)-loaded CMGP, CMGP-Fe(III) is heated at 10 °C/min to 800 °C at dry Ar atmosphere. There are three significant weight loss platforms: first platform is from room temperature to about 160 °C, the weight loss is 9.70%, and there is a corresponding endothermic peak(115.6 °C), that is because of the adsorbed water, crystal water and small-molecules biomass of adsorbents decomposition; second platform is from 160 °C to 550 °C, the weight loss is 54.96%, and there are two exothermic peaks(270.5 °C and 334.7 °C), that may be due to the macromolecule biomass intense decomposition and the reduction of ferric iron by the reducing gas(CO) or the biological carbon; third platform is from 580 °C to 800 °C, the weight loss is about 6.96%, and there is a corresponding endothermic peak (616.2 °C) and a exothermic peak(757.2 °C), that is probably ascribed to the residue carbon of adsorbents decomposition and the continuing reduction process. Fig.11 shows the XRD results of different products of Fe(III)-loaded gel. Firstly, the Fe(III)-loaded gel was heated in the alumina crucibles to the designated temperature at a rate of 10 °C/min in the vacuum tube furnace, then the sample is cooled in the furnace to room temperature at Ar atmosphere. The XRD patterns show that the products of iron and Fe₃O₄ can be obtained by heating at 800 °C, while if the sample is heated at 700 °C, Fe₃O₄ is produced as the main iron-born component.

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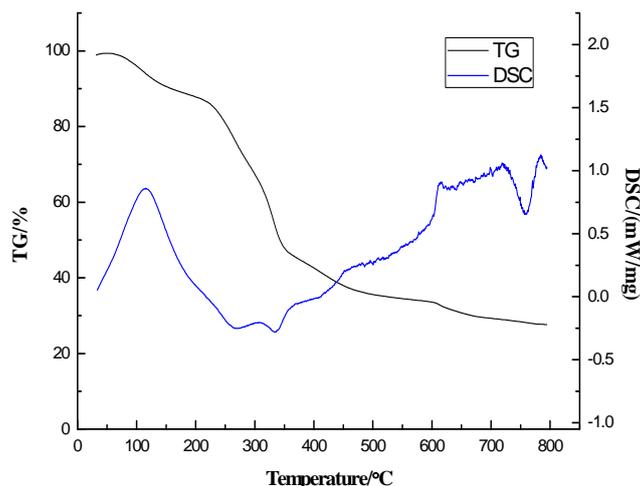


Fig. 10 Curves for the TG/DSC of Fe(III)-loaded CMGP gel combusted at 10°C/min in the flowing dry Ar gas

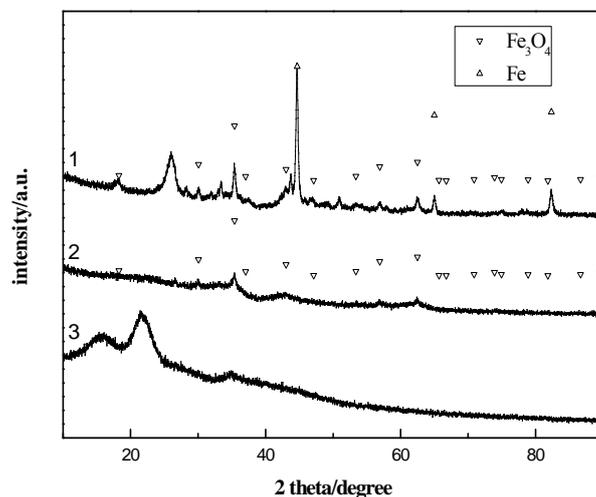


Fig. 11 XRD patterns of Fe(III)-loaded garlic peel and its combustion products (1-800°C; 2-700°C; 3-CMGP-Fe(III) gel)

3 Conclusions

The present study showed that garlic peels, an abundant agricultural resource, can find an application as a biological adsorbent of Fe(III) ions from aqueous solutions. The process kinetics was found to follow the pseudo-second-order rate equation. The Langmuir adsorption isotherm models were applied to equilibrium data at different initial concentrations. FTIR results verify the changes of the surface properties of adsorbent materials after the modification of CMGP gel and reveal that the carboxyl and polyphenolic hydroxyl groups are involved in Fe(III) ions adsorption. The Fe(III) loaded adsorbent can produce fine iron powder through thermal reduction, providing a possibility of iron resources recycling. This work may give the good idea for good use of this kind of special agricultural waste, and also can help to recover the waste iron ions in the waste water produced in the hydrometallurgical processes.

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通过大蒜渣凝胶吸附选择性去除和回收 Fe (III)

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摘要: 在湿法冶金工艺中去除铁是一个相当普遍的挑战,传统的方法如降水可能会造成严重的二次污染和资源浪费。在目前的研究中,我们尝试了一种廉价有效的技术,通过吸附到大蒜残留凝胶上去除铁离子。提出了一种用氢氧化钙改性果皮的简单化学改性方法。结果表明,430 在没有 Fe (III) 水解的情况下,90% 吸附的最佳平衡 pH 约为 2.5。在 60 分钟内达到吸附平衡。吸附过程可分别用 Langmuir 模型和拟二级动力学方程很好地描述。发现 Fe (III) 离子的最大吸附容量为 1.4mol / kg。大蒜皮中含有的次磺酸,果胶酸,多酚和蒜氨酸组分被推断为负责将 Fe (III) 离子吸收到凝胶上的主要配体。制备了涉及镍和铜湿法冶金工艺的模拟解决方案,以测试 Fe (III) 的选择性去除行为,并讨论了吸附铁的回收和再利用的可能性。435 目前的工作可能有助于回收和再利用真正的湿法冶金工艺中的大量铁资源,并为许多传统的湿法冶金工艺带来更加环保,清洁和缩短的工艺。

关键词: 铁吸附; 大蒜废物; 湿法冶金; 减少污染; 零价铁