



Title	Desorption of cadmium from a natural Shanghai clay using citric acid industrial wastewater
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Title: Desorption of Cadmium from a Natural Shanghai Clay Using Citric Acid Industrial Wastewater

Article Type: Research Paper

Keywords: Electrokinetic remediation; sorption; desorption; citric acid industrial wastewater (CAIW); MINTEQA2; soil remediation

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Abstract: The sorption/desorption characteristics of heavy metals onto/from soil particle surfaces are the primary factor controlling the success of the remediation of heavy-metal contaminated soils. These characteristics are pH-dependent, chemical-specific, and reversible; and can be modified by enhancement agents such as chelates and surfactants. In this study, batch experiments were conducted to evaluate the feasibility of using citric acid industrial wastewater (CAIW) to desorb cadmium from a natural clay from Shanghai, China at different soil mixture pHs. It can be observed from the results that the proportion of cadmium desorbed from the soil using synthesized CAIW is generally satisfactory, i.e., > 60%, when the soil mixture pH is lower than 6. However, the proportion of desorbed cadmium decreases significantly with increase in soil mixture pH. The dominant cadmium desorption mechanism using CAIW is the complexation of cadmium with citric acid and acetic acid in CAIW. It is concluded that CAIW can be a promising enhancement agent for the remediation of cadmium-contaminated natural soils when the environmental conditions are favorable. As a result, CAIW, a waste product itself, can be put into productive use in soil remediation.

Desorption of Cadmium from a Natural Shanghai Clay Using Citric Acid Industrial Wastewater

Ying-Ying Gu¹ and Albert T. Yeung^{2,*}

Novelty Statement

The paper presents the results of an investigation on the potential use of citric acid industrial wastewater (CAIW) as an enhancement agent in electrokinetic remediation of cadmium contaminated high acid/base buffer capacity natural soil. The desorption characteristics of cadmium of a natural clay from Shanghai for a range of soil mixture pH values were evaluated experimentally. The information is vital for the use of CAIW as an enhancement agent for electrokinetic remediation, as the soil pH changes throughout the remediation process. Moreover, it establishes the viability of a productive use of a waste material to remediate cadmium contaminated high buffer capacity natural soil. The paper should be published in the Journal of Hazardous Materials as many readers of the journal are interested in soil remediation technologies.

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Desorption of Cadmium from a Natural Shanghai Clay Using Citric Acid Industrial Wastewater

Ying-Ying Gu¹ and Albert T. Yeung^{2,*}

Highlights

- CAIW is very effective in desorbing cadmium from soil particle surfaces at soil mixture pHs of lower than 5.
- The cadmium desorption efficiency of CAIW also depends on the initial sorbed concentration of cadmium on the soil particle surface.
- Complexion of cadmium with citric acid and acetic acid are the dominant mechanisms for cadmium desorption in the soil mixture pH range of 4 to 8.
- CAIW may be a promising enhancement agent for the remediation of heavy metal-contaminated soils.

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1 **Desorption of Cadmium from a Natural Shanghai Clay**
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3 **Using Citric Acid Industrial Wastewater**

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33 21 **ABSTRACT:** The sorption/desorption characteristics of heavy metals onto/from
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34 | acid and acetic acid in CAIW. It is concluded that CAIW can be a promising
35 | enhancement agent for the remediation of cadmium-contaminated natural soils
36 | when the environmental conditions are favorable. As a result, CAIW, a waste
37 | product itself, can be put into productive use in soil remediation.

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39 | **KEYWORDS: Electrokinetic remediation; sorption; desorption; citric acid industrial**
40 | **wastewater (CAIW); MINTEQA2; soil remediation**

41 | 42 | **1. INTRODUCTION**

43 | Cadmium contamination of soil and groundwater is a worldwide environmental
44 | problem, posing threats on both public health and the environment. For example, vegetable
45 | cropland, paddy, and natural soils of many sites in Shanghai, China are contaminated by
46 | cadmium [1, 2]. The natural concentration of cadmium in soil is between 0.1-1.0 mg Cd/kg
47 | soil and a cadmium concentration of higher than 10 mg Cd/kg soil can be toxic for plants [3].
48 | Cadmium is a significant metal contaminant in the environment due to its high water
49 | solubility and toxicity [4], and its ability to cause *itai-itai* disease [5, 6].

50 | When cadmium is sorbed on soil particle surfaces or precipitated, it is immobile and
51 | thus difficult to be extracted by most soil remediation technologies [7, 8]. Therefore, an
52 | effective soil remediation technology must be able to transform and maintain cadmium in a
53 | mobile state to facilitate its removal from soil. Electrokinetic remediation of fine-grained
54 | soils has many advantages over many existing remediation technologies because an electrical
55 | gradient is a much more effective driving force in transporting fluid and chemical flows
56 | through fine-grained soils than a hydraulic gradient [7]. It applies a direct-current electric

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57 field across the contaminated soil through electrodes inserted into the contaminated soil.
58 Contaminants are transported by electroosmosis, electromigration, and/or electrophoresis.
59 Meanwhile, the fluids at the anode and cathode undergo electrolytic decomposition. An acidic
60 environment is developed at the anode, favoring the solubilization of metal ions from soil
61 particle surfaces. At the cathode, an alkaline environment is formed which enhances sorption
62 of metals onto soil particle surfaces and precipitation of metallic oxides. Therefore, there is a
63 need for an effective and economical technology to control the sorption/desorption
64 characteristics of soil particle surfaces, so as to make the contaminant mobile to enhance the
65 effectiveness of the remediation technology.

66 The sorption/desorption characteristics of soil particle surfaces are dynamic,
67 pH-dependent, and reversible. In general, keeping a low pH environment in soil enhances the
68 extractability of heavy metals. However, achieving an acidic environment may be difficult for
69 natural soils of high acid buffer capacity [9, 10]. Nonetheless, the sorption/desorption
70 characteristics of soil particle surfaces can be modified by the use of enhancement agents
71 including chelates, surfactants, organic acids, etc. [6, 9, 11-13]. Among these enhancement
72 agents, EDTA has been demonstrated to be one of the most effective in desorbing heavy
73 metals from soils of high buffer capacity [6, 9, 11, 14]. The injection of EDTA into
74 contaminated Milwhite kaolinite effectively desorbs lead and cadmium from soil particle
75 surfaces and mobilizes them during electrokinetic extraction [6, 11, 13, 15]. However, the
76 high cost and non-selective nature of EDTA have limited its use in the remediation of
77 metal-contaminated sites [16, 17]. Moreover, EDTA resists biodegradation and can be sorbed
78 on soil particle surfaces. As a result, soils remediated by EDTA or similar chelating agents
79 may not be suitable for future agricultural use [18, 19].

80 In this study, citric acid industrial wastewater (CAIW) was studied as a potential
81 cost-effective enhancement agent for electrokinetic remediation of metal-contaminated soils,

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82 so as to put a waste product into effective and economical use. However, the pH of the
83 contaminated soil may be changed by the electrokinetic remediation process as a function of
84 time and space. Therefore, a comprehensive study of the performance of CAIW at different
85 soil mixture pHs was conducted in this study.

86 CAIW is a recalcitrant dark-colored wastewater of low pH containing large quantities
87 of citric acid, acetic acid, and other impurities. Although many techniques have been
88 developed for the treatment of CAIW [20-22], effective and economical disposal of the large
89 quantity of CAIW being produced routinely remains a challenge. As weak organic acids and
90 heavy metal chelates, citric acid and acetic acid have been used successfully to promote
91 efficient removal of heavy metals from soils [14, 18, 19, 23-25]. CAIW was also used as the
92 chelating agent in the phytoremediation of heavy metal contaminated soils by Chen *et al.* [26].
93 Their results indicate that CAIW is effective in improving the availability of different forms
94 of copper in the contaminated soil for the plant, although it is still less efficient than EDTA.
95 However, the potential application of CAIW in electrokinetic remediation technology as an
96 enhancement agent has yet to be studied. Therefore, the study presented in this paper was
97 conducted.

98 CAIW may be a cost-effective chelating agent source in lieu of commercial citric acid
99 and acetic acid so as to put a waste product to a productive use. As weak organic acids, they
100 would not lower the soil pH to a level detrimental to the environment [27]. Moreover, a very
101 low soil pH may reverse the electroosmotic flow direction, thus reducing the efficiency of
102 electrokinetic remediation of metal-contaminated soils [6]. Therefore, CAIW may serve as an
103 efficient and economical enhancement agent in electrokinetic remediation of
104 cadmium-contaminated fine-grained soil.

105 In this study, batch experiments were conducted to extract cadmium from a natural
106 clay soil from Shanghai, China. Effects of soil mixture pH, initial sorbed concentration of

107 cadmium on the soil particle surface, and CAIW concentration on cadmium desorption from
108 clay particle surfaces were studied. Moreover, desorption tests using different **individual**
109 constituents of CAIW were carried out to evaluate their **individual** contribution towards the
110 desorption ability of CAIW.

112 **2. MATERIALS AND METHODS**

113 **2.1 Materials**

114 **2.1.1 Soil**

115 The soil used in this study is a natural clay soil collected at depths of 0.5-1.0 m in
116 Nanhui District, Shanghai, China. The soil was air-dried, pulverized, screened through a
117 2-mm opening sieve, homogenized, autoclaved for 120 minutes, and then stored for later use.
118 The soil was autoclaved to remove the microorganisms in the soil to eliminate possible
119 biodegradation of any chemical in the system, so as to avoid misinterpretation of the results.
120 The soil is classified as CL, i.e., inorganic clays of low to medium plasticity, in accordance
121 with the Unified Soil Classification System [28]. In fact, it is a slightly alkaline clay soil of
122 low plasticity. The background concentration of cadmium in the soil is negligible relative to
123 the cadmium concentration to be spiked into the soil in this study. Physicochemical properties
124 of the soil are tabulated in Table 1 and more details are given in Gu *et al.* [9].

126 **2.1.2 Citric Acid Industrial Wastewater (CAIW)**

127 Citric acid industrial wastewater (CAIW) is a dark-colored waste liquid of low pH
128 containing large quantities of organic acids and other impurities [29]. It is the wastewater
129 generated by the manufacturing process of citric acid. The CAIW used in this study was
130 synthesized in the laboratory and its properties are tabulated in Table 1. The CAIW was
131 synthesized so that its chemical composition is representative of most real-life CAIW.

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132 | ~~However~~Moreover, the well-defined chemical composition of the synthesized CAIW can
133 | facilitate interpretation of the experimental results and repeatability of the study.

135 | **2.2 Experimental Procedures**

136 | Different series of batch experiments were conducted to evaluate the desorption
137 | characteristics of CAIW by systematically varying the experimental parameters and
138 | procedures as described.

140 | **2.2.1 Desorption Edge using CAIW**

141 | Desorption edge experiments were conducted following the method described by
142 | Torrens *et al.* [30]. One gram of soil specimen and 10 mL of 0.5, 1, 2, 3, 4, or 5 mM
143 | Cd(NO₃)₂ solution were added to a 50-mL centrifuge. The soil mixtures were shaken for
144 | 24 hours using a wrist action shaker at 25°C to allow cadmium to sorb on soil particle
145 | surfaces before they were centrifuged at 4,000 rpm for 15 minutes. The centrifuge tubes
146 | containing the mixtures were then weighed before and after the supernatants were decanted to
147 | determine the volume of cadmium solution retained in the soil. Cadmium concentration in the
148 | supernatant was diluted with 1% HNO₃ and measured using a Perkin Elmer Analyst 300
149 | flame atomic absorption spectrometer. The sorbed concentration of cadmium on the soil
150 | particle surface was thus determined.

151 | Afterwards, 10 mL of synthesized CAIW was added to each soil mixture to serve as
152 | the purging solution. A control test was also conducted using 10 mL of deionized water in
153 | lieu of CAIW. The ~~pHs of the~~ soil mixture pHs were adjusted to different values by adding
154 | 0.1 and/or 1 M HNO₃ or 0.1 and/or 1 M NaOH. The adjusted pH of the soil mixture was
155 | measured by a pH meter. The soil mixtures were shaken for 5 hours and then centrifuged. The
156 | supernatant was diluted with 1% HNO₃ and analyzed for cadmium concentration using

157 atomic absorption spectrometry to determine the quantity of cadmium desorbed. Each test
158 was performed in duplicate to ensure repeatability of the experiments.

2.2.2 *Effect of CAIW Concentration on Cadmium Desorption*

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161 Two milliliters of 2.5 mM Cd(NO₃)₂ solution was added to each 1-g dry soil specimen
162 and the soil mixture was shaken for 24 hours to allow cadmium to sorb onto soil particle
163 surfaces. Practically all the cadmium in the solution is sorbed on soil particle surfaces.
164 Therefore, the initial sorbed concentration of cadmium on soil particle surfaces was
165 560 mg Cd/kg of soil in this series of experiments. Afterwards, 0, 0.5, 1.0, 2.0, 5.0, or 8.0 mL
166 of synthesized CAIW was added to each soil mixture and diluted to 10 mL with deionized
167 water. The ~~pH of the~~ soil mixture pH was adjusted to 5.3 by adding 1 M HNO₃. The soil
168 mixtures were shaken for 5 hours and then centrifuged before the supernatants were analyzed
169 for cadmium concentration.

2.2.3 *Effects of Individual CAIW Constituents on Cadmium Desorption*

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172 CAIW contains large quantities of organic acids and other ions such as Cl⁻, SO₄²⁻,
173 Ca²⁺, and NH₄⁺. These constituents may affect desorption of cadmium from soil particle
174 surfaces differently. In this series of desorption experiments, purging solutions of deionized
175 water, synthesized CAIW, or individual constituents of CAIW, including 2.96 g/L of Na₂SO₄,
176 1.4 g/L of CaCl₂, 0.134 g/L of NH₄Cl, 3 g/L of citric acid, and 5.5 g/L of acetic acid, were
177 prepared to evaluate their individual effects on desorption of cadmium from the natural clay.

178 Two milliliters of 2.5 mM Cd(NO₃)₂ solution of was added to 1 g of soil placed in a
179 50-mL centrifuge tube and shaken for 24 hours to allow cadmium to sorb on soil particle
180 surfaces. Afterwards, 8 mL of the purging solution was added to each mixture. The ~~pHs of the~~
181 soil mixture pHs were adjusted by addition of 0.1 and/or 1 M HNO₃ or 0.1 and/or 1 M NaOH

182 and the adjusted pH was measured by a pH meter. After 5 hours of shaking, the soil mixtures
183 were centrifuged and the supernatants were diluted with 1% HNO₃ for determination of
184 cadmium concentration.

186 3. RESULTS AND DISCUSSION

187 3.1 Desorption Edge

188 The effects of CAIW on desorption of cadmium from soil at different soil mixture pH
189 values are compared to those of deionized water in Figure 1. Ten milliliters of 0.5 mM
190 Cd(NO₃)₂ solution was added to each 1-g soil specimen in this particular series of
191 experiments, and tThe resulting initial sorbed concentration of cadmium on soil particle
192 surfaces in this series of experiments was measured to be 530 mg Cd/kg soil. It can be
193 observed that deionized water can desorb approximately 40% of cadmium from soil particle
194 surfaces at soil mixture pH 5. When the soil mixture pH is increased to 7, desorption of
195 cadmium from soil becomes less than 2%. However, with the addition of CAIW, the
196 proportion of desorbed cadmium is increased to more than 85% at soil mixture pH 5. In the
197 soil mixture pH range of 5 to 8, CAIW increases the proportions of desorbed cadmium by 20%
198 to 45% more than those by deionized water at the same soil mixture pHs. Furthermore, the
199 upper bound of soil mixture pH limit for cadmium desorption is extended from 7 to 10. The
200 results indicate the ability of CAIW to solubilize the cadmium sorbed on soil particle surfaces
201 is considerably better than that of deionized water.

202 Desorption curves of cadmium using CAIW of different initial sorbed concentrations
203 are depicted in Figure 2. The drastic influence of soil mixture pH on desorption of cadmium
204 from soil particle surfaces at all initial sorbed concentrations of cadmium on the soil particle
205 surface is evidently demonstrated. At soil mixture pHs lower than 5, the proportion of
206 cadmium desorbed from soil by CAIW is very high, i.e., > 85%. However, the proportion

207 decreases significantly with increase in soil mixture pH when the soil mixture pH is greater
208 than 5. However, the decrease in proportion of cadmium desorbed per unit increase in soil
209 mixture pH is practically independent of the initial sorbed concentration. When the soil
210 mixture pH is further increased to a threshold value in the range of 9.5 to 11.5, the proportion
211 of cadmium desorbed becomes negligible. The threshold soil mixture pH depends on the
212 initial sorbed concentration. The higher is the initial sorbed concentration, the higher is the
213 threshold soil mixture pH.

214 It can also be observed that the proportion of cadmium desorbed increases with the
215 initial sorbed concentration of cadmium on the soil particle surface. The phenomenon is more
216 prominent when the soil mixture pH is higher than 5. When the initial sorbed cadmium
217 concentration is low, cadmium ions are primarily sorbed onto high selectivity sorption sites.
218 However, cadmium ions are getting sorbed onto low selectivity cation exchange sites when
219 the initial sorbed cadmium concentration is increased. As a result, the increase in cadmium
220 density on soil particle surfaces favors the cation exchange process by NH_4^+ , Ca^{2+} , etc. in
221 CAIW, thus increasing the proportion of cadmium desorbed. In a high pH environment, the
222 surface charges on soil particles become more negative as indicated by the zeta potential of
223 the soil particle surface, leading to an enhancement of specific sorption of heavy metals [9,
224 31]. Moreover, precipitation of insoluble cadmium hydroxides and cadmium carbonates
225 makes desorption more difficult.

3.2 Effect of CAIW Concentration on Cadmium Desorption

228 The effect of CAIW concentration on cadmium desorption at pH 5 is shown in Figure
229 3. The relative concentration of CAIW is defined to be the diluted concentration of CAIW
230 used in the experiment normalized by relative to the original concentration of the synthesized
231 CAIW. Deionized water alone can only desorb 24.7% of cadmium sorbed on the soil particle

232 surface at soil mixture pH 5. The addition of CAIW increases the proportion of cadmium
233 desorbed. The higher is the relative concentration of CAIW, the higher is the proportion of
234 cadmium desorbed from the soil. However, the increase in the proportion of cadmium
235 desorbed per unit increase in relative concentration of CAIW decreases with increase in
236 relative concentration of CAIW. Nonetheless, CAIW of relative concentration of 0.8 can
237 desorb more than 80% of the sorbed cadmium from the soil, indicating the original
238 concentration of CAIW is adequate to function as an enhancement agent to desorb cadmium
239 from soil satisfactorily at soil mixture pH 5. Therefore, CAIW can be used as it is produced
240 without much processing.

242 3.3 Contributions of Individual Constituents of CAIW to Cadmium Desorption

243 The results of cadmium desorption using individual constituents of CAIW at different
244 soil mixture pHs are depicted in Figure 4. It can be observed that citric acid is the most
245 efficient purging solution followed by acetic acid, indicating desorption of cadmium from soil
246 by CAIW can be mostly attributed to the presence of citric acid and acetic acid. Citric acid is
247 a weak triprotic acid which can form mononuclear, binuclear, or polynuclear and bi-, tri-, and
248 multidentate complexes with heavy metals, depending on the type of metallic ion [32]. Acetic
249 acid is a low-weight organic acid which can form soluble monodentate complexes with heavy
250 metals. The higher stability of citrate-cadmium complexes leads to the higher efficiency of
251 citric acid in desorbing cadmium from soils than acetic acid, as observed in the tabulated
252 stability constants of cadmium complexes in Table 2.

253 The enhancing effects of weak organic acids on desorption of heavy metal have been
254 studied by many researchers [14, 17, 33-37]. However, most of these studies use these low
255 molecular weight organic acids as a conditioning solution to lower the soil mixture pH but do
256 not investigate in detail the effects of soil mixture pH on the desorption efficiency of heavy

257 metals from soil.

258 Other ionic species in CAIW also enhance the extraction of cadmium from the soil.

259 NH_4^+ , SO_4^{2-} , and Cl^- have a slight ability to desorb cadmium from soil by forming

260 complexes with cadmium, such as $\text{Cd}(\text{NH}_3)_4^{2+}$, CdSO_4 , CdCl^+ and CdCl_2 . Cations such as

261 Ca^{2+} and Na^+ can enhance the solubilization of cadmium at lower soil mixture pHs by

262 competing for sorption sites on soil particle surfaces with cadmium ions [38].

263 Cadmium desorption by different constituents of CAIW is pH-dependent. Cadmium

264 extractability from soil decreases when the soil mixture pH is increased from 5 to 9. The

265 results are in good agreement with those of many previous studies. Naidu and Harter [39]

266 reported that desorption of cadmium using organic ligands including acetate and citrate

267 decreased with increase in soil mixture the pH of the ligand solution. Yuan *et al.* [37] observed

268 that desorption of cadmium by citric acid decreased sharply with increase in soil mixture pH.

269 Mustafa *et al.* [37] demonstrated experimentally that an increase in equilibrium soil mixture

270 pH from 5.5 to 6.0 can reduce cadmium desorption from goethite using $\text{Ca}(\text{NO}_3)_2$

271 significantly.

272 However, opposite results revealed by some other studies indicate that metal

273 desorption by citric acid decreased at low soil mixture pHs [40, 41]. The difference can be

274 easily explained by the different physicochemical properties of soils used for the experiments.

275 The soils used by these researchers carry positive surface charges at low soil mixture pHs,

276 causing the sorption of negatively charged complexes on soil particle surfaces. However, the

277 natural soil used in this study has no point of zero charge (PZC) and always carries negative

278 surface charges [9]. Negatively charged complexes are thus repelled by negatively charged

279 soil particle surfaces into the solution phase.

280 When the soil mixture pH increases from 5 to 7, the proportion of cadmium desorbed

281 from soil particle surfaces using citric acid is much higher than those using other constituents

of CAIW, probably due to complexation of cadmium with citric acid. As the pK_a values of citric acid are 3.13, 4.76, and 6.40, the ratio of $[\text{Citrate}]^{3-}$ increases significantly and dominates at soil mixture pHs of higher than 7.0, accounting for the high desorption rate of cadmium from soil particle surfaces. However, the logarithmic stability constant of $\text{Cd}[\text{Citrate}]$, i.e., 11.3, is less than the solubility of $\text{Cd}(\text{OH})_2$ ($pK_{sp} = 13.6$), resulting in precipitation of cadmium with OH^- with increase in soil mixture pH [37].

The interactions of different chemical species in the cadmium-CAIW system without soil at different pHs were simulated by the software MINTEQA2 to better understand the desorption mechanisms of cadmium using CAIW. The total concentration of cadmium in the system for the simulation is 0.5 mM. The concentrations of different cadmium species in the solution system versus system pH are shown in Figure 5. At pHs 2 to 4.5, Cd^{2+} , CdCl^+ , and $\text{CdSO}_4(\text{aq})$ are the dominant species in the system. However, the zeta potential of the soil particle surface is less negative in this range of soil mixture pHs, resulting in the desorption of a high proportion of cadmium. When soil mixture pH is in the range of 4.5 to 8.5, most of the cadmium in the system complexes with citric acid to form $\text{Cd}[\text{Citrate}]^{\square}$ or $\text{Cd}[\text{Citrate}]_2^{4-}$, or with acetic acid to form $\text{Cd}[\text{Acetate}]^+$. Although cadmium is sorbed onto soil particle surfaces by stronger electrostatic forces in this range of soil mixture pHs, the formation of soluble cadmium chelates significantly enhances the desorption of cadmium from soil particle surfaces by CAIW at neutral soil mixture pHs. Cadmium precipitates become the dominant species when the pH is higher than approximately 9. It is very difficult to solubilize precipitated cadmium again.

4. CONCLUSIONS

Several conclusions can be drawn from this experimental study on desorption of cadmium from a natural Shanghai clay using synthesized CAIW:

- 307 a. CAIW is very effective in desorbing cadmium from soil particle surfaces at soil
308 mixture pHs of lower than 5. However, the proportion of cadmium desorbed
309 decreases significantly with increase in soil mixture pH. When the soil mixture pH is
310 higher than a threshold value, the proportion of cadmium that can be desorbed
311 becomes negligible. The threshold soil mixture pH increases with initial sorbed
312 concentration of cadmium on the soil particle surface.
- 313 b. The cadmium desorption efficiency of CAIW also depends on the initial sorbed
314 concentration of cadmium on the soil particle surface. The proportion of cadmium
315 desorbed increases with increase in initial sorbed concentration.
- 316 c. Complexion of cadmium with citric acid and acetic acid are the dominant mechanisms
317 for cadmium desorption in the soil mixture pH range of 4 to 8. At higher soil mixture
318 pHs, precipitated cadmium is difficult to be desorbed.
- 319 d. CAIW may be a promising enhancement agent for the remediation of heavy
320 metal-contaminated soils. The use of CAIW as an enhancement agent can put the
321 waste product to a productive use.

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1

Table 1. Properties of materials

Property	Value
Soil	
Specific gravity	2.73
Liquid limit (%)	36
Plastic limit (%)	19
Plasticity index (%)	17
pH (1:1)	8.29
Organic content (%)	0.18%
Electrical conductivity (dS/cm)	0.339
Cd concentration (mg/kg)	1.6
Synthesized CAIW	
pH	3.87
Concentration of citric acid (mg/L)	3000
Concentration of Acetic acid (mg/L)	5500
Concentration of SO_4^{2-} (mg/L)	2001.1
Concentration of Ca^{2+} (mg/L)	504.5
Concentration of Cl^- (mg/L)	984.4
Concentration of NH_4^+ (mg/L)	45.1
Concentration of Na^+ (mg/L)	958.9

2

1 **Table 2. Accumulative formation constants of cadmium complexes with**
2 **citrate and acetate [42]**

Cd Complexes	Accumulative Formation Constants
CdH ₂ (Citrate) ⁺	7.9
CdH(Citrate)	3.05
Cd(Citrate) ⁻	3.10
Cd(Acetate) ⁺	1.5
Cd(Acetate) ₂	2.3
Cd(Acetate) ₃ ⁻	2.4

where (Citrate) = C₃H₅O(COO)₃³⁻
 (Acetate) = CH₃COO⁻

3

Figure 1
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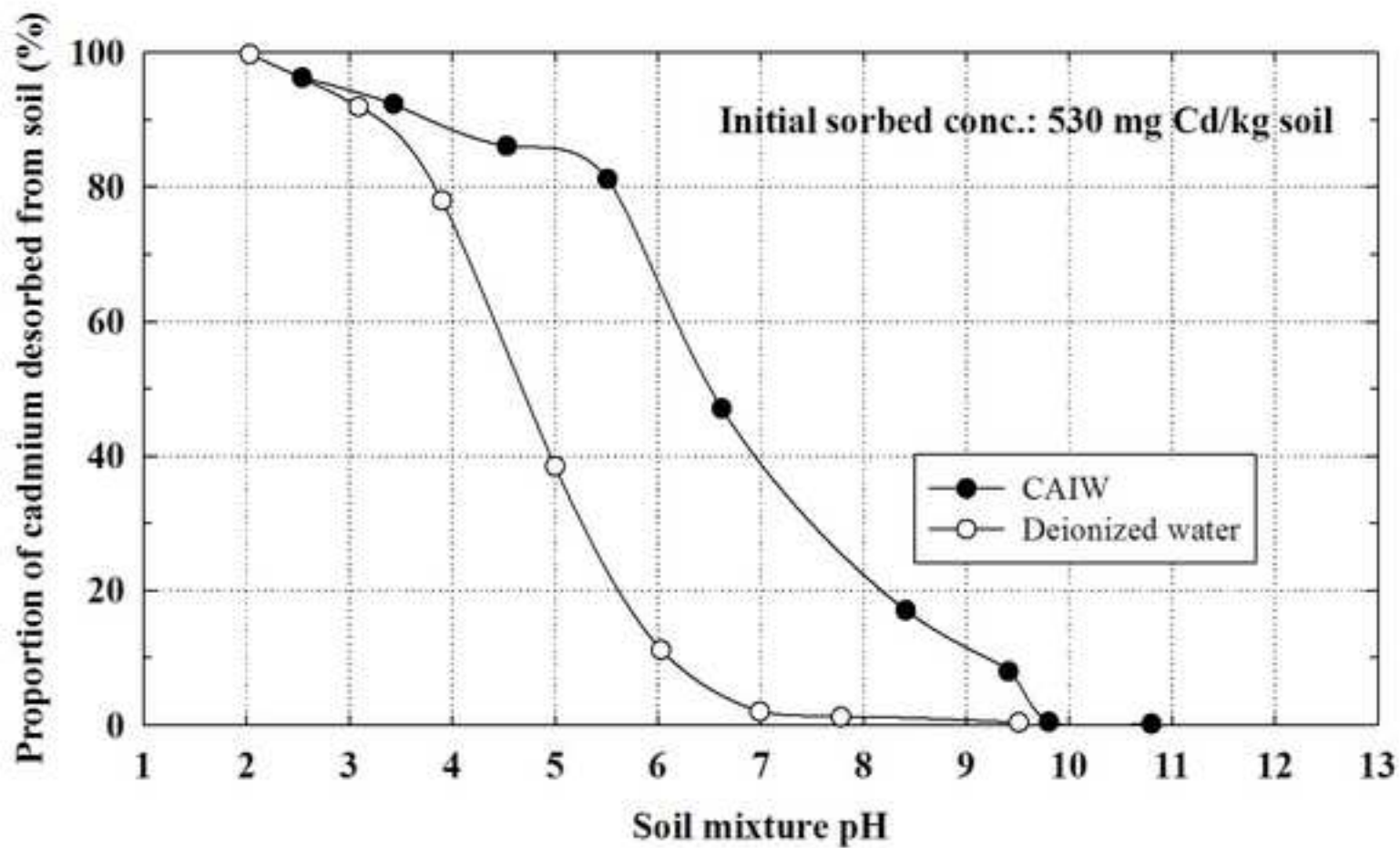


Figure 1. Comparison of cadmium desorption by CAIW and deionzed water

Figure 2
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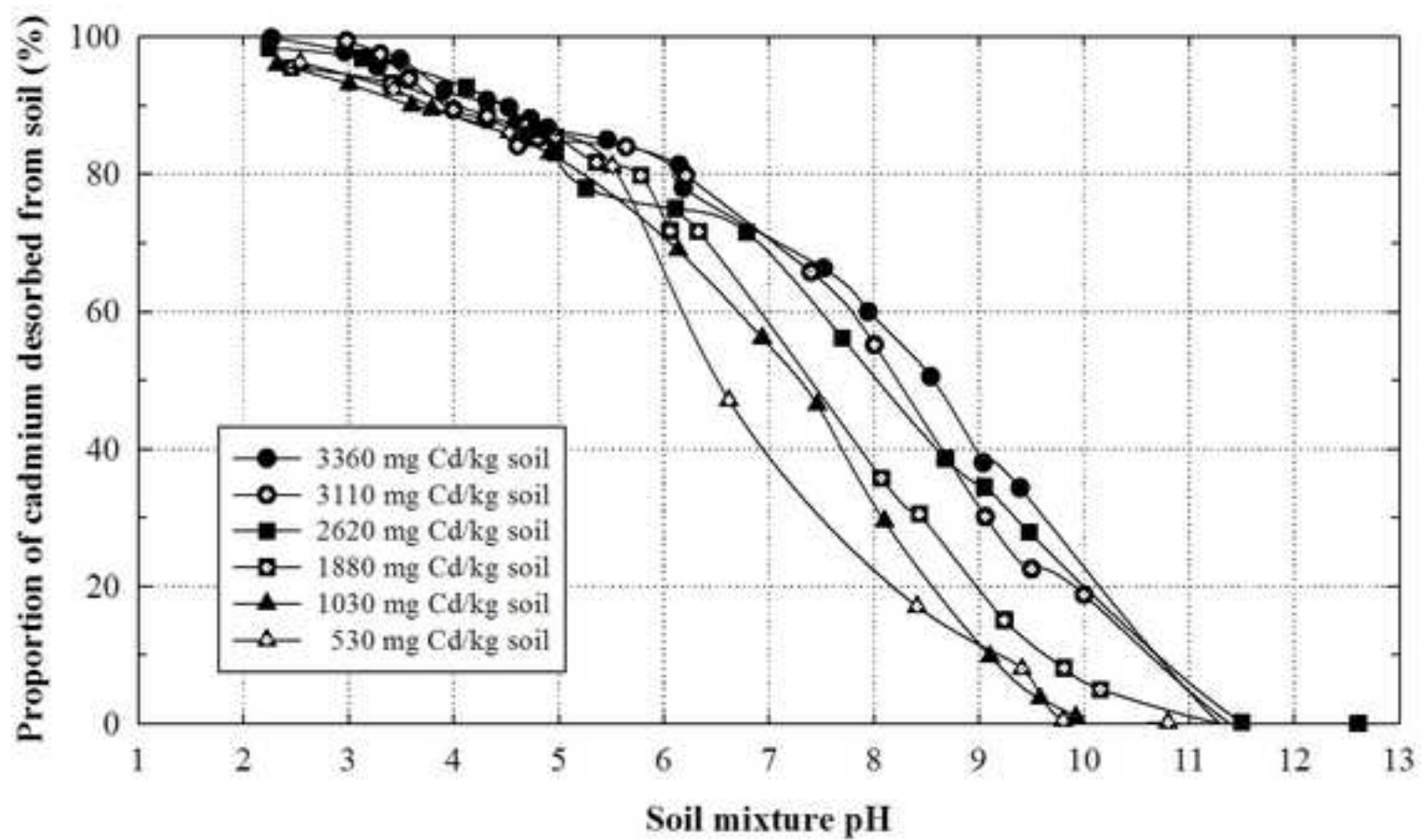


Figure 2. Desorption of cadmium of different initial sorbed concentrations by CAIW

Figure 3
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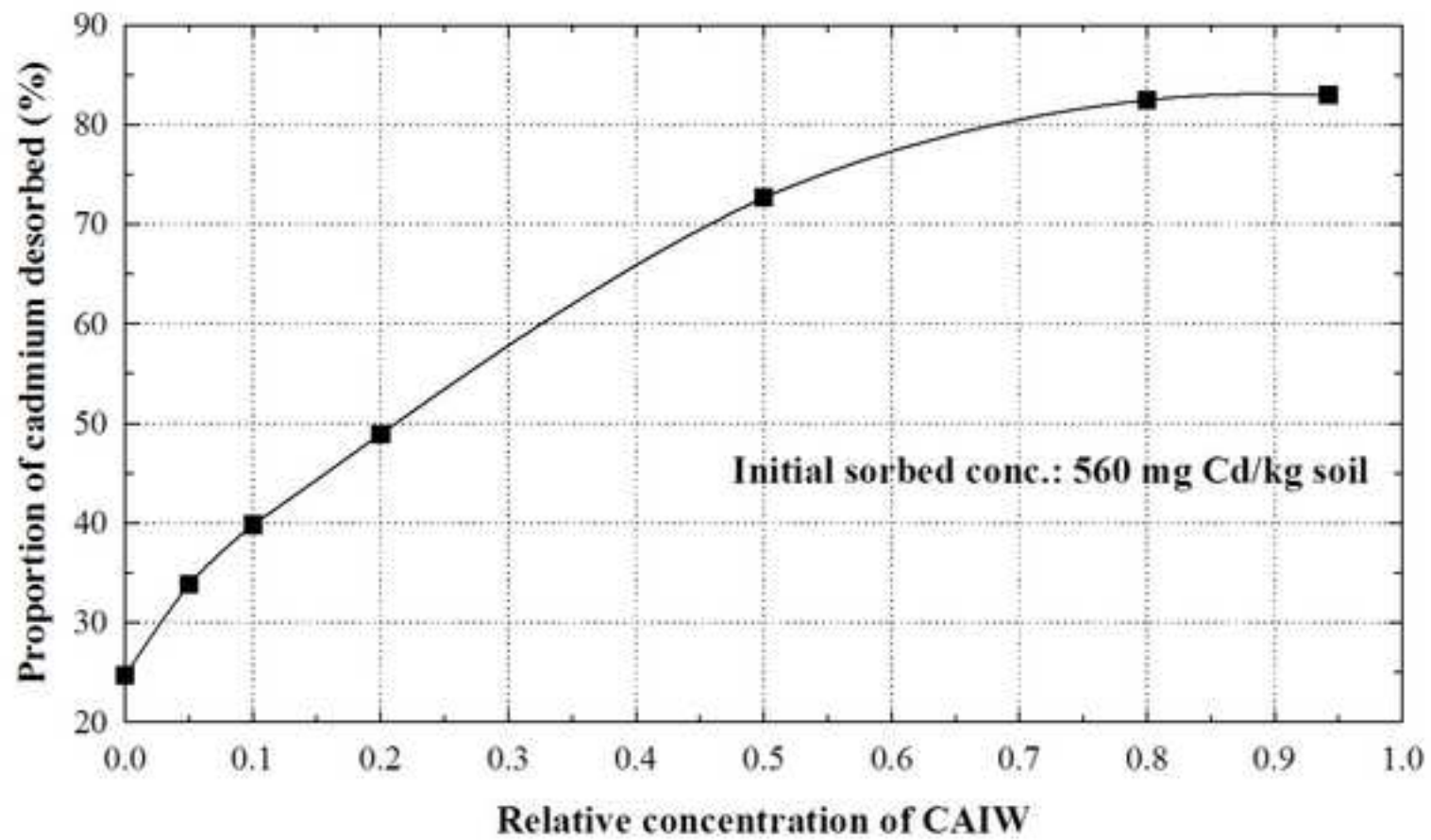


Figure 3. Effect of CAIW concentration on cadmium desorption

Figure 4
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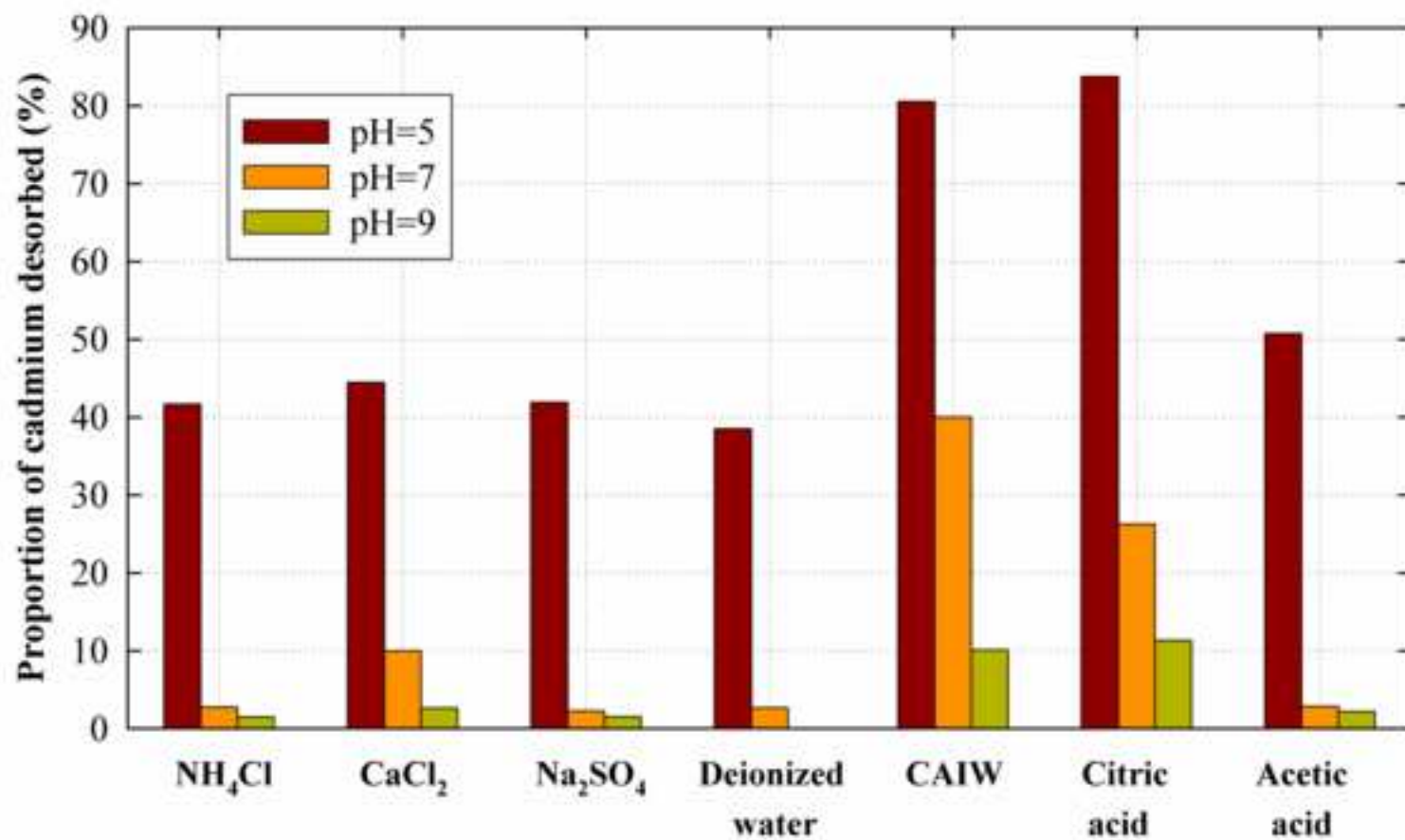


Figure 4. Effect of different constituents on cadmium desorption

Figure 5
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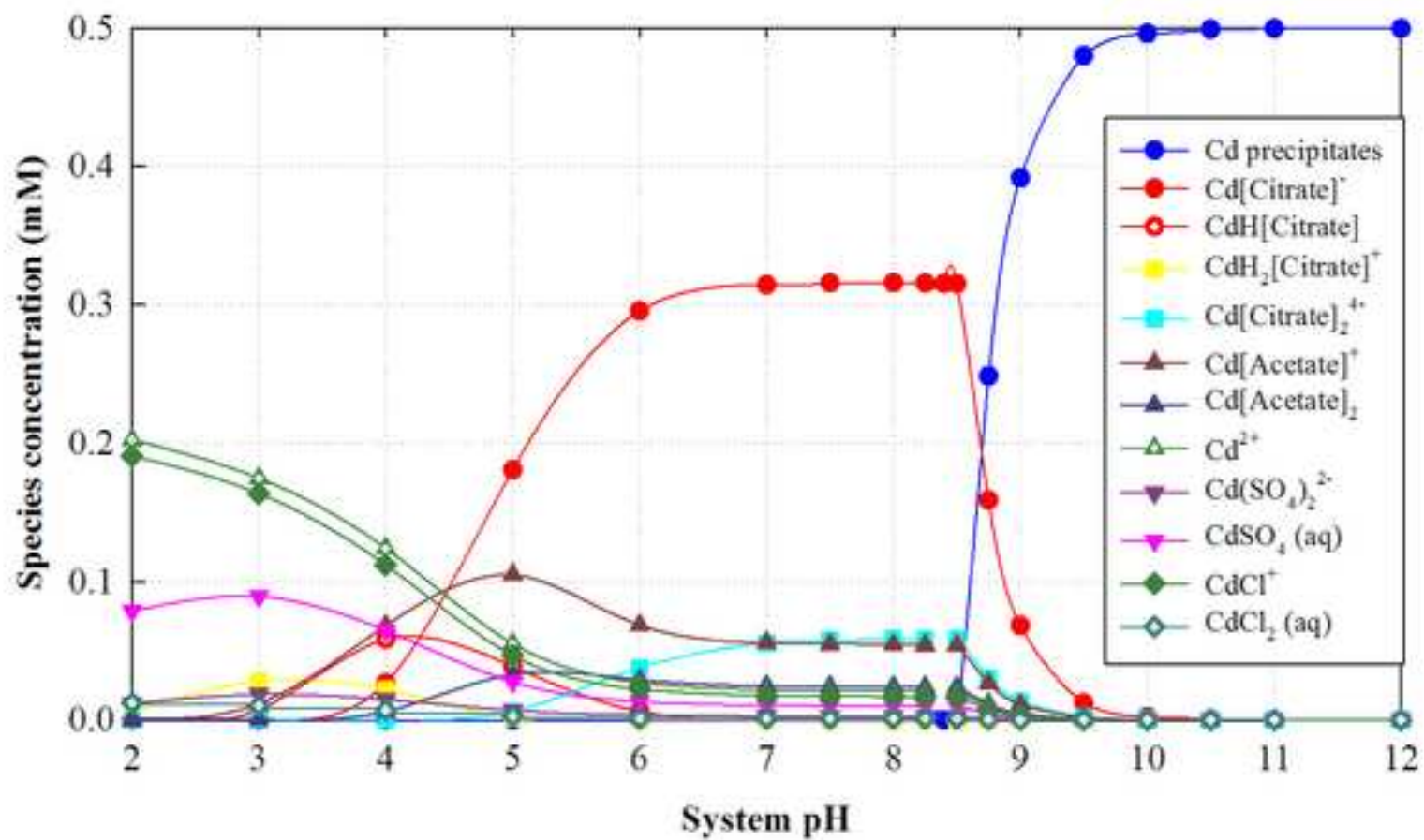


Figure 5. Concentrations of different species in CAIW-Cd (0.5 mM) system by MINTEQA2