PHYSIOCHEMICAL INFLUENCE OF SOIL MINERALS ON THE ORGANIC REDUCTION OF SOIL CHROMIUM

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ABSTRACT

The physiochemical influence of soil minerals (Bentonite, Kaolinite, Diatomite, Rutile and Ferrihydrite) on the organic reduction of chromium (VI) has been investigated with Oxalic acid as the organic reductant. The effect of pH and particle sizes of the soil minerals were also investigated. Results showed that with 0.1mol/dm^3 *concentration of Oxalic acid, the concentration of chromium(VI) remaining was 0.28, 0.34, 0.38, 0.46 and 0.52mg/kg for Bentonite, Rutile, Diatomite, Kaolinite and Ferrihydrite respectively whereas at 0.5 mol/dm*^{3} *of oxalic acid, the concentration of chromium reduced to 0.20, 0.26, 0.30, 0.38, and 0.44mg/kg for Bentonite, Rutile, Diatomite, Kaolinite and Ferrihydrite. Increased concentration of oxalic acid increased the reduction of chromium(VI) to chromium(III). At pH 5.0, the concentration of chromium(VI) left was 0.28, 0.34, 0.38, 0.46 and 0.52mg/kg for Bentonite, Rutile, Diatomite, Kaolinite and Ferrihydrite while at pH 2.5, concentration was 0.16, 0.22, 0.26, 0.34 and 0.43mg/kg respectively. At particle size of 47-42 microns, concentration of chromium(VI) was 0.28, 0.34, 0.38, 0.46, 0.52mg/kg for the same order of the soil minerals. At micron sizes of 33-29 and 28-25 ranges the concentration of chromium(VI) left was 0.23, 0.29, 0.33, 0.41 and 0.47mg/kg for both micron sizes and corresponding minerals as well. These results showed that above 33-29 micron sizes, the influence of particle size was negligible.*

Keywords: soil minerals, organic reduction, chromium (VI), oxalic acid

INTRODUCTION

Chromium (Cr) pollution is widely known for its adverse health effect. For example, dregs of chromium are produced during manufacturing Cr-containing alloys and salts. These waste materials contain significant amount of chromium, which could be leached out due to water filtration and/or ground water fluctuation (James, 1996). Chromium contamination of soils and water is also caused by improper disposal of Cr-containing waste water and sludge as used for corrosion inhibition and electroplating industries.

When released into the environment, chromium exists mainly as hexavalent chromate ($HCrO_4^-$ / CrO_4^{2-}, noted as Cr(VI) and trivalent forms noted as Cr(III)). Chromium species at different oxidation states show substantially different physical and chemical properties. Cr(VI) is an oxidant with high solubility and mobility in soils and aquifers as well as high toxicity to human and ecosystem, whereas Cr(III) has lower mobility , mostly precipitated as hydroxides or absorbed onto mineral surfaces. As a result, contamination of Cr(VI) is often controlled by Cr(VI) reduction using various reductants, such as zero valent iron (Blowes *et al.*, 1997), ferrous ions (Bond & Fendorf, 2003) and organic compound (James & Bartlelt, 1983) . Most of these studies were aimed at reducing Cr(VI) in the aqueous phase relevant to groundwater remediation by delivering reductants in solids or liquid forms.

CHROMIUM IN THE SOIL

Reclaiming chromium contaminated soils, sediments and waste water could be by development of an efficient remediation process for the conversion of Cr(VI) to Cr(III). The low rate of reduction of soil chromium by widely distributing organic matters has lead to adoption of some reduction technologies by industries. Since chromium(VI) can be reduced without intervention, the rate of natural attenuation is unacceptably slow. Thus, supplying reductants into the soil is becoming necessary for increasing Cr(VI) reduction. This remediation by reduction in the soil will lower the hazards associated with high level of chromium(VI) without changing the total chromium content of the soil, and in so doing , the potentially harmful ecological and human health effects of Cr(VI) enriched soil are minimized (Tzou *et al*., 2003).

The detoxification of chromium contaminated soil have been considered over the ages as an effective method of reclaiming such soils for agricultural purposes as well as sediments and waste water. Since organic matter is widely distributed in soil and aquatic systems, low chromium(VI) reduction rates inhibit the adoption of chromium reduction technologies in industries. Scientists have been aware of chromium(VI) reduction catalysed by soil minerals, however most of the studies focused on the use of semi-conductors as catalysts with ultraviolet irradiation to accelerate the redox reactions (Elovitz & Fish, 1994).

Soil chromium has been known to pass through a rather slow natural reduction process leading to the conversion of toxic chromium(VI) to non-toxic chromium(III). Although chromium(VI) is reduced to chromium(III) to some extent without intervention, rates of natural attenuation can be unacceptably slow thus supplying reductants into soils and ground water is becoming attractive for accelerating chromium(VI) reduction. Inorganic treatments may include H_2S injection (Kim *et al*., 2001), aqueous Fe(II) injection (Seaman *et al*., 1999) and use of reduced iron (Fe) solids in permeable reactive barriers (Blowes *et al*., 1997) .

THE CHEMISTRY OF CHROMIUM

Proposed organic–based Cr(VI) reduction strategies have included application of various carbon source such as manure, molasses and organic acids (Blowes *et al*., 1997) .The effectiveness of organic carbon in reducing chromium(VI) depends on the concentration of the contaminant, reactivity of organic carbon and microbial activity (Elovitz & Fish, 1995) . The extent of chromium(VI) reduction in contaminated sediments also depends on native and added organic carbon quantity and chromium(VI) reduction rates constants for many species are pH dependent, becoming slow under neutral to alkaline condition (Elovitz & Fish, 1995). Chromium reduction by organic carbon also occurs through microbially mediated pathways, as soil micro organism can also contribute to chromium(VI) reduction through release of ferrous iron, sulphides and reactive organic intermediates. Mineral surfaces also may catalyze chromium(VI) reduction by organic carbon (Deng & Stone, 1996a).

The rate of chromium(VI) reduction by fluorescent light in the presence of organic material with or without specific soil minerals have been reported (Tzou *et al*., 2003). Experimental results had shown that dissolved organic compounds reduced Cr(VI) slowly under laboratory lights, however Cr(VI) reduction was greatly enhanced when growth chamber light was applied (Tzou *et al*., 2003) . Low photon flux (laboratory light) only enhances Cr(VI) reduction by organics when Fe(III) was also present because the Fe(II)-Fe(III) redox couple accelerated electron transfer and decrease electrostatic repulsion between reactants. Laboratory light was required to initiate Cr(VI) reduction catalyzed by TiO_2. Light catalyzed Cr(VI) reduction by smectites and ferrihydrite could only occur when greater light energy was provided with a growth chamber light (Tzou *et al*., 2003) .

The reduction of Cr(VI) by HEDTA was found to be rapid under growth chamber light compared with that by other organic ligands. Conversely, citrate and oxalate showed higher Cr(VI) reduction rates than HEDTA in the presence of Fe(III) under laboratory light . It is possible that the complexation of Fe(III) with citrate or oxalate made these organic compounds better reductants and the redox potentials became more positive by forming complexes with Fe(III) (Stumm, 1992).

For contamination residing in vadose-zone, mixing a reactive agent in solid form is often difficult to manipulate and using a liquid reactant run the risk of further spreading the contaminants to previously contaminated zones.

A new technology, *In Situ* Gaseous Reduction (ISGR) was therefore developed by Pacific North West National Laboratory by using the gas Hydrogen Sulphide (H_2S) as the reactant (Thornton & Amonetti, 1997). Laboratory experiments showed that over 90% of chromium(VI) could be reduced to chromium (III) in soil by H_2S treatment.

A field study at White sand missile range, New Mexico USA also demonstrated over 70% of chromium immobilization through its reduction to Cr(III). The field demonstration further showed that Hydrogen Sulphide could be handled safely for field application (ASME, 1999). Secondary contamination of H_2S could be consumed by reaction with iron oxide in soils (Cantrell *et al*., 2003). Elemental sulphur was the major products of sulphide oxidation under anaerobic condition (Lan *et al*., 2005). The aqueous phase processes are relevant to ISGR treatment in the Vadose-zone because even though the treatment is by gaseous reductants, Cr(VI) reduction occur in the water film or mineral particle surfaces formed under suitable humidity (Hua & Deng, 2003).

It has been shown that the rate of Cr(VI) reduction by Ferrous iron was significantly increased by several minerals including geothite(α-FeOOH), Lepidocrocite(γ- FeOOH), Montmorillonite(bentonite),kaolinite(china clay) and amorphous silica, but not by aluminium oxide (Buerge & Hug, 1998). In another study mineral such as aluminium oxide (γ-Al_2O_3), goethite and titanium dioxide (TiO_2) were found to catalyze Cr(VI) reduction by α- hydroxyl carboxylic acid and their esters, α- carboxyl carboxylic acids and substituted phenols (Deng & Stone, 1996b). From experimental knowledge, reducing agents decolourise acidified potassium heptaoxodichromate (VI) from orange to colourless. This theoretically involves a change in the oxidation state of chromium from (VI) to (III). This reduction in oxidation state depicts itself as a colour change characteristics of ions in the transition series.

Clay minerals possess large surface area because of their fine particulate sizes, their role in typical reactions is to lower the activation energy by exposing the reaction to large surface area. The reduction and colour change is governed by chemical redox equation.

$$6C_2O_4^{2-} + 2Cr_2O_7^{2-} + 14H^+ \rightarrow 12CO_2 + 4Cr^{3+} + 7H_2O \qquad (1)$$

Experimental results showed that dissolved organic compounds reduced chromium (VI).

Since different minerals possess different catalytic reactivities (Torrents & Stone, 1991), and it is reasonable to expect different efficiencies for either catalyzing or inhibiting Cr(VI) reduction when Cr(VI) contaminated waste water comes in contact with various minerals. The impact of soil minerals on Cr(VI) reduction by oxalic acid has not been reported. As part of the effort to better understand the reaction between Cr(VI) and $C_2O_4^{2-}$, this research aims at investigating the effects of selected minerals, PH and reductants concentration on the rate of chromium (VI) reduction at different concentrations of oxalic acid.

MATERIALS AND METHODS

The soil minerals used in the analysis were (A) - Bentonite, (B) – Rutile, (Titanium dioxide), (C)- Ferrihydrite, (D)- Kaolinite, and (E)- Diatomite. They were obtained in their natural state, dried and pulverised to different particle size ranges required.

The particle size ranges were as follows:

1. 47-42 microns
2. 41-38 microns
3. 37-34 microns
4. 33-29 microns
5. 28-25 microns

The soil samples were procured from Akaraka industries limited, Aboh Mbaise, Imo State, Anita industries, Afo Oru Mbaise and Invar Chemicals limited Aba and they are all soil mineral processing industries. The lumps were washed and dried and later pulverised using the pendulum pulverizer (pp) and sieve analysis carried out on each sample to obtain the range of particle sizes of interest. The obtained samples were labelled as A_1, A_2, A_3,A_4 and A_5 where A is Bentonite and 1….5 are the micron sizes. The same was done for B,C,D and E. The samples were preserved in dry plastic containers ready for analysis.

All solutions were prepared with distilled deionized water. Glassware was cleaned with 6 M HCL and thoroughly rinsed with distilled deionized water. Chromium (VI) stock solution was prepared from $Na_2Cr_2O_7$ (ACS reagent-grade; Sigma Chemicals, St Louis, MO). Inorganic salts, Sodium Nitrate were obtained from Fisher (Pittsburgh, PA) (reagent-grade chemicals). Indicators and buffers for chromium(VI) analysis were obtained from Fisher (diphenylcarbazide). Organic compressing agents were obtained from Sigma (N-hydroxyethyl-ethylenediamine-triacetic acid, HEDTA) and Sodium Oxalate without further purification.

50cm^3 of the different concentration of the standard $Na_2Cr_2O_7$ were measured and introduced into labelled samples bottles as 0.2, 0.4, 0.6, 0.8 and 1.0 mg/kg. The labelled sample bottles were covered with aluminium foil and finally enclosed in a black polyethylene bag to prevent influence of light. This was done so as to preclude light catalyzed reduction of chromium (Tzou *et al*., 2003).

PROCEDURE FOR ORGANIC REDUCTION OF CHROMIUM USING DIFFERENT CONCENTRATIONS OF OXALIC ACID

The particle size range of the soil minerals were between 47-25 microns. A sample of 0.5g each of the five soil sample was placed in five different 250cm^3 beaker and 20cm^3 of 1.0mg/kg of dichromate was thereafter added. To each of the beaker a mixture of 10cm^3 of 0.1mol/dm^3 of oxalic acid, 2cm^3 of $NaN0_3$, 5cm^3 of 6.0m HCl , 5cm^3 of sodium oxalate and 2cm^3 of HEDTA were added and the mixture shaken thoroughly and stored in a plastic sample bottle. The five samples were enclosed with an aluminium foil and finally enclosed in a black polyethylene bag ready for analysis.

Determination at variable pH

The same analyses were carried out using the different pH buffers for each soil mineral at concentration of 0.1mol/dm^3 oxalic acid. The samples were protected with aluminium foil and enclosed in a black polythene bag.

Determination at variable particle size ranges

The analysis was carried out using different particle micron sizes of the soil minerals with 0.1mol/dm^3 concentration of the organic reductant-oxalic acid. The samples were also protected with aluminium foil and enclose in a polythene bags for further analysis.

Analytical methods

Chromium (VI) concentration in the supernatant solution was determined using the diphenylcarbazide (DPC) colorimetric method. According to preliminary experiments, the reduction of Cr(VI) by the organic compounds in acidified sample solution may produce a positive interference with the DPC method. This interference could be avoided by adding diphenylcarbazide to Cr(VI) before acidifying the solution: the interference from light absorption by organic reactants or their products at 540nm in the DPC procedure were negligible. This absorbance was measured in a 1-cm cell at 540nm on a spectrophotometer (spectronic 20 by thermofisher). The solution was filtered through a 0.2µm-pore-size membrane filter before Cr(VI) analyses of the supernatant solution was carried out. The spectrum gave the wavelength in nanometers of the remaining chromium which was there after extrapolated from the calibration curve to obtain the concentration in mg/kg of the remaining chromium (VI). Total chromium was analysed using Atomic Absorption Spectroscopy (AAS).

RESULTS AND DISCUSSION

Chromium(VI) reduction by different oxalic acid concentration in the presence of soil minerals

Five soil minerals (Bentonite, Rutile, Kaolinite, Diatomite and Ferrihydrite) were selected to assess the effect of soil minerals on the Cr(VI) reduction at different reductant-oxalic acid concentration. Initial concentration of Cr(VI) was 1.0mg/kg and the concentration of oxalic acid was varied from 0.1M – 0.5M. Results in Table 1 show the different oxalic acid concentration effect on the $Na_2Cr_2O_7$ used as the source. This unreduced Cr(VI) has a gradual decrease as the oxalic acid concentration increases. The influence of soil minerals on Cr(VI) reduction using oxalic acid could be assessed by comparing the concentration of unreduced Cr(VI) in each soil sample. Table 2 shows the trend of increased oxalic acid (0.1 -0.5 mol/dm^3) and corresponding reduced Cr(VI) concentration from 0.72 – 0.80mg/kg for Bentonite, 0.66 – 0.74 mg/kg for TiO_2, 0.62 – 0.70 mg/kg for Diatomite, 0.54 – 0.062 mg/kg for Kaolinite and 0.48 – 0.56 mg/kg for Fe(II) respectively. This reaction occurred at the solid-solution interface and shows that increased oxalic acid concentration increases the reduction of Cr(VI). Fig. 1 shows that Bentonite had more influence on the reduction process than other soil minerals used in the analysis. The plot of Cr (VI) against oxalic acid concentration in Fig. 1 shows the relationship between reductant and reduced Cr(VI). Ferrihydrite showed the least effect and this is attributed to the fact that the reaction was surface-catalysed process. The time of reaction did not allow for dissolution of ferrihydrite and subsequent release of Fe(III).

TABLE 1

Concentration of Chromium in Mg/Kg

Oxalic acid Mol/dm^3	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
0.1	0.28	0.34	0.38	0.46	0.52
0.2	0.26	0.32	0.36	0.44	0.50
0.3	0.24	0.30	0.34	0.42	0.48
0.4	0.22	0.28	0.32	0.40	0.46
0.5	0.20	0.26	0.30	0.38	0.44

TABLE 2

Concentration of Oxalic Acid and Reduced Chromium (VI) Mg/Kg

Oxalic acid Mol/dm^3	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
0.1	0.72	0.66	0.62	0.54	0.48
0.2	0.74	0.68	0.64	0.56	0.50
0.3	0.76	0.70	0.66	0.58	0.52
0.4	0.78	0.72	0.68	0.60	0.54
0.5	0.80	0.74	0.70	0.68	0.56

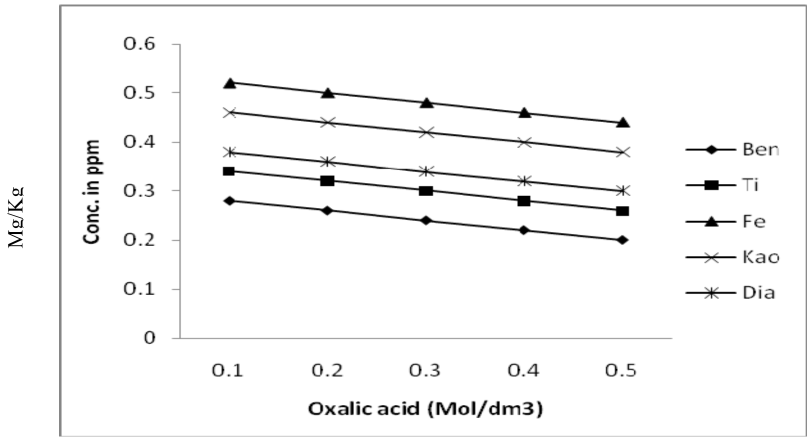

Figure 1. Concentration of Chromium (VI) *versus* Oxalic acid at pH 5.0.

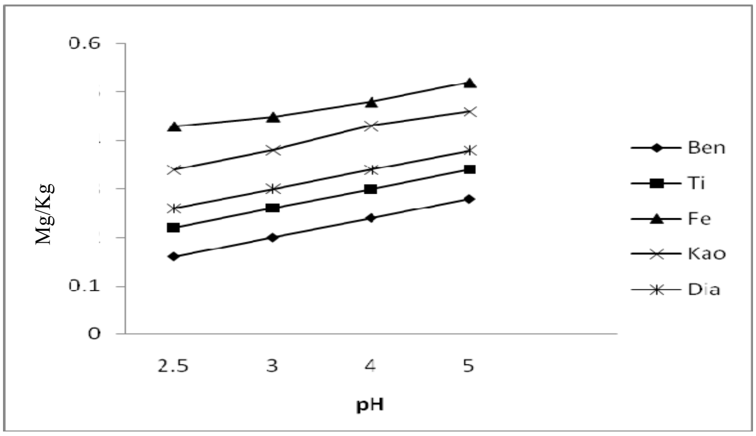

Figure 2. Concentration of Chromium (VI) *versus* pH.

Chromium(VI) reduction by oxalic acid at different pH values

Chromium (VI) reduction by oxalic acid in the systems with Bentonite, TiO_2, Diatomite, Kaolinite and Ferrihydrite was examined from pH 2.5 -5.0 using pH buffers to control the pH (Table 3a, Fig. 2). These pH values indicate that the reaction was carried out in acidic medium.

From Table 3a at pH of 5.0, Cr(VI) reduced by Bentonite is 0.72mg/kg, 0.66mg/kg in TiO_2 , 0.62mg/kg in Diatomite, 0.54mg/kg in Kaolinite and 0.48mg/kg in Ferrihydrite. Fig. 2 shows no marked difference in the trend of reduced Cr(VI) reduction plot. Within this pH ranges of 2.5 – 5.0, it could be deduce that Cr(VI) reduction takes place to obtain Cr(III) which is less mobile. The concentration Cr(VI) remaining is as shown in Table 3b.

TABLE 3a

PH and Concentration of Reduced Chromium (VI) Mg/Kg

PH	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
5.0	0.72	0.66	0.62	0.54	0.48
4.0	0.76	0.70	0.66	0.57	0.52
3.0	0.80	0.74	0.67	0.62	0.55
2.5	0.84	0.78	0.74	0.66	0.58

TABLE 3b

Concentration of Chromium (VI) Mg/Kg at different PH values

PH	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
5.0	0.28	0.34	0.38	0. 64	0.52
4.0	0.24	0.30	0.34	0.43	0.48
3.0	0.20	0.26	0.30	0.38	0.45
2.5	0.16	0.22	0.26	0.34	0.43

Chromium (VI) reduction by oxalic acid using different particle sizes of soil minerals

Since the impact of soil minerals on chromium (VI) reduction by carboxylic acid as reported by (Deng & Stone, 1996a) showed surface catalyzed reduction using oxalic acid in this case, the particle size was varied to determine the influence of soil mineral particle sizes on the reduction of Cr(VI). The concentration of reduced Cr(VI) for Bentonite is 0.72mg/kg for 47-42 micron size, 0.74mg/kg for 41-38 micron size, 0.76mg/kg for 37-28 micron size and 0.77mg/kg for both 33-28 and 28-25 micron sizes (Table 4a, Fig. 3). The micron sizes of 28-25 and 33-28 being very low particle size have the same amount of Cr(VI) reduced in all the soil samples. This shows that any further decrease in particle size from 33 micron, will not have any significant change in the amount of Cr(VI) reduced. Since this is surface-catalyzed reduction and the reaction takes place at the solid-solution interface, it then shows that particle size have marked effect on the reduction of Cr(VI). When the particle size is high that is micron sizes of 47-41 and 41-37, the concentration of reduced chromium is low compared to the small particle sizes. Reduction in particle size provides more surface area for the reduction process to occur.

The presence of soil mineral as examined in this study is not expected to change the stoichiometry of equation (1) but only the amount of chromium(VI) reduced at a particular time. Chromium(VI) is reduced to chromium (III) to some extent without intervention though the rate of this natural attenuation is unacceptably slow. Since clay minerals possess large surface area because of their fine particulate size, their role as established in this typical reaction is to lower the activation energy by exposing the reaction to large surface area. The difference in the catalytic reactivity of these soil minerals as shown in the graphs correspond to the finding of (Torrents & Stone, 1991).

TABLE 4a

Particles Sizes (μ) and Concentration of Reduced Chromium (VI) Mg/Kg

Particle Size	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
47-42	0.72	0.66	0.62	0.54	0.48
41-38	0.74	0.68	0.64	0.56	0.50
37-34	0.76	0.70	0.66	0.58	0.52
33-29	0.77	0.71	0.67	0.59	0.53
28-25	0.77	0.71	0.67	0.59	0.53

TABLE 4b

Concentration of Reduced Chromium (VI) Mg/Kg at Variable Particle Sizes (μ)

Particle Size	Bentonite	TiO_2	Diatomite	Kaolinite	Fe(III)
47-42	0. 28	0.34	0.38	0.46	0.52
41-38	0.26	0.32	0.36	0.44	0.50
37-34	0.24	0.30	0.34	0.42	0.48
33-29	0.23	0.29	0.33	0.41	0.47
28-25	0.23	0.29	0.33	0.41	0.47

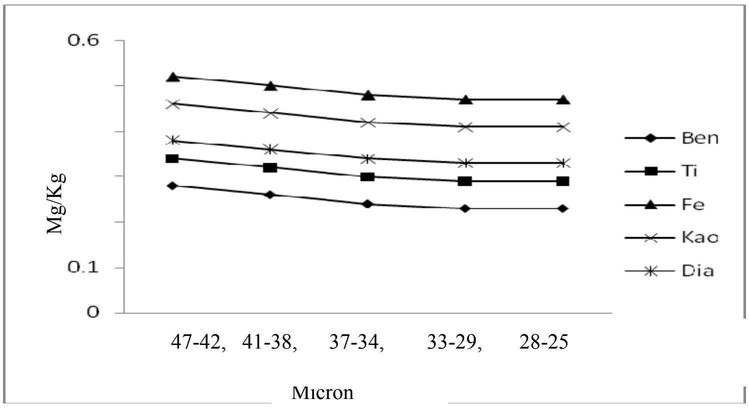

Figure 3. Concentration of chromium (VI) *versus* particle sizes.

Influence of pH on chromium(VI) reduction by oxalic acid

Lower pH *(i.e.* pH 2.5) accompanied with higher concentration of oxalic acid resulted in significantly a higher Cr(VI) reduction. The enhancement of Cr(VI) reduction by Oxalic acid at lower pH is probably due to the electrostatic effect. Protons helped the association of Cr(VI) with Oxalic acid; that is, H^+ decreased the negative charge and repulsion of these two reactants and facilitated subsequent electron transfer. The increased Cr(VI) reduction by soil mineral at lower pH was expected because redox reaction consumed H^+ according to equation (1). The chromium(VI) retention and adsorption by soil minerals studied by (Tzou *et al*., 2003) confirmed the result that lower pH reduce chromium(VI) more than higher pH values.

CONCLUSION

Results have shown that soil minerals exhibit different influences on the organic reduction of chromium, (Deng & Stone, 1996a). The change in the reductant concentration also shows that increased oxalic acid concentration affects the reduction process positively. At higher concentration of oxalic acid *i.e.* 0.5mol/dm^3 , the unreduced chromium(VI) was found to be 0.20mg/kg for Bentonite, 0.26mg/kg for TiO_2, 0.30 mg/kg for Diatomite, 0.44 mg/kg for Ferrihydride. Lower concentration of oxalic acid *i.e.* 0.1 mol/dm^3 reduce chromium (VI) to 0.28, 0.34, 0.38, 0.46 and 0.52 mg/kg in that same order.

The catalytic effect exhibited by soil mineral at different physiochemical conditions, shows that the reduction of Cr(VI) by organic compound in aquatic environments depends not only on the constituents that participate directly in the stoichiometric reaction but also on other naturally occurring constituents of the soil mineral which could catalyze or inhibit the reaction (Deng & Stone, 1996a).

The reduction of chromium using oxalic acid as reductant for different soil minerals show different efficiencies in the reaction as being observed in Tables 1, 2 and 3. It could be deduced that Bentonite, Rutile, Diatomite, Kaolinite and Ferrihydrite all have positive influence on the reduction of chromium(VI).

Reclamation of chromium contaminated soil or water can thus be effected by organic reduction in the presence of soil minerals at rates which depends on concentration of the reductant on one part, pH and particle size of the soil minerals on the other part.

In all situations, optimum reduction rates exists for each soil mineral as well as particle size. The structure of the soil minerals differs and consequently their specific surface areas show marked difference. Kaolinite and Bentonite though are anhydrous alumino silicates but the double sheet of tetrahedral and octahedral shapes are so closed that the surface area of Kaolinite is reduced as compared to Bentonite which on its own possess a hydration pocket with free ions (K^+, Na^+ *etc*…).Diatomite on the other hand differ markedly in structure compared to rutile and ferrihydrite.

Bentonite surfaces affect the efficiency of charge transfer among chromophores through charge and steric effects. Steric effects dominate the reaction of a given phyllosicate. It is unlikely that Cr(VI) could access the inner surfaces of Bentonite and could be reduced to Cr(III) in the inter-layer. Chromium(VI) reduction should have occurred in the planar or external surfaces of Bentonite. The experiment were stopped after 24hrs because of the dissolution of ferrihydrite, which could result in the release of Fe(III) and prevent the accurate determination of Cr(VI) by the colorimetric method.

The result of this study showed that Cr(VI) reduction by Oxalic acid using Bentonite, Diatomite, Rutile, Kaolinite and Ferrihydrite give positive effects. It was deduced that the study was a surface-catalyzed Cr(VI) reduction by soil minerals and the dissolution of soil minerals was not allowed. This avoided the individual reactivity of ions within the soil mineral.

Reducing Cr(VI) to less toxic and mobile Cr(III) is one of the appropriate and safe method for Cr(VI) remediation. In the aquatic environment, Cr(VI) was greatly affected by pH, organic compounds and particle sizes of the soil minerals available. The solution pH has a large influence on the reduction of Cr(VI) by organic-reductant.

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