Environ Geol (2007) 53:387–397
DOI 10.1007/s00254-007-0654-5

ORIGINAL ARTICLE

Field investigations and laboratory simulation of clogging in Lixi tailings dam of Jinduicheng, China

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Received: 27 November 2006 / Accepted: 15 January 2007 / Published online: 10 February 2007

Abstract Clogging is one of the most important factors affecting the stability of the tailings dams. Firstly, this work investigates the clogging materials of Lixi tailings dam using ICP-AES, X-ray powder diffraction (XRD) and SEM analysis methods. The ICP-AES results indicate that Fe is the dominant element in the clogging materials. The iron contents of clogging samples collected from 2# radial-well pipe and the access hole of the starter dam are 54.35 and 40.24%, respectively. XRD spectra show that ferric hydroxide is the main initial component of the clogging materials. Other compounds such as akaganeite, hematite and goethite are products from ferric hydroxide transformation. Therefore, the clogging materials are a mixture of ferric hydroxide and its converted products. The clogging materials commonly exist in an amorphous form with a cluster microstructure when viewed under SEM. Secondly, this work uses a continuous flow column to simulate clogging in the laboratory, and the clogging materials are analyzed with XRD and SEM. The chemical analysis indicates that the iron content of the clogging materials from the experiment is 45.43%. XRD spectra show that hematite is the only compound detected. The clogging materials generated experimentally are also in amorphous cluster microstructure when viewed under SEM.

Keywords Tailings dam · Clogging · Iron compounds · Experiment analysis

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Introduction

Tailings dam, an important part of the mining operation, is a repository for the fine materials resulting from mineral extraction and processing. The stability of a tailings dam is critical for safety and environmental safeguarding. The impact of tailings dam failures on the environment and other issues related to the tailings dam are reported frequently (Murillo et al. 1999; Domènech et al. 2002; Macklin et al. 2003; Bonilla-Valverde et al. 2004; Fernández et al. 2005; Morillo et al. 2005; Van Niekerk and Viljoen 2005; Lei and Watkins 2005). Many factors play a role in affecting the stability of the tailings dam, including clogging of the drainage systems. Few special studies have been carried out to investigate clogging of tailings dams although clogging in other areas has been widely reported (Seki et al. 1998; Fleming et al. 1999; Rinck-Pfeiffer et al. 2000; Ross et al. 2001; Islam et al. 2001; Islam and Singhal 2004; VanGulck et al. 2003; VanGulck 2003; VanGulck and Rowe 2004; Fuchs et al. 2004; Rowe and McIsaac 2005).

Lixi tailings dam is located at Jinduicheng Molybdenum Group Mining Corporation (JMGMC) in Shaanxi Province, China as shown in Fig. 1. The tailings dam is currently 164.5 m in height. The upstream embankment method was used during construction of the tailings dam. The main body currently contains 16 sub-dams. The pipes of the access hole are often covered with slurry-like materials that have resulted in an increase in the elevation of the seepage line. This poses a risk to the stability of the tailings dam, and further investigation of the clogging mechanism is required.

The objectives of this paper are to identify the dominant element in the clogging materials, to analyze

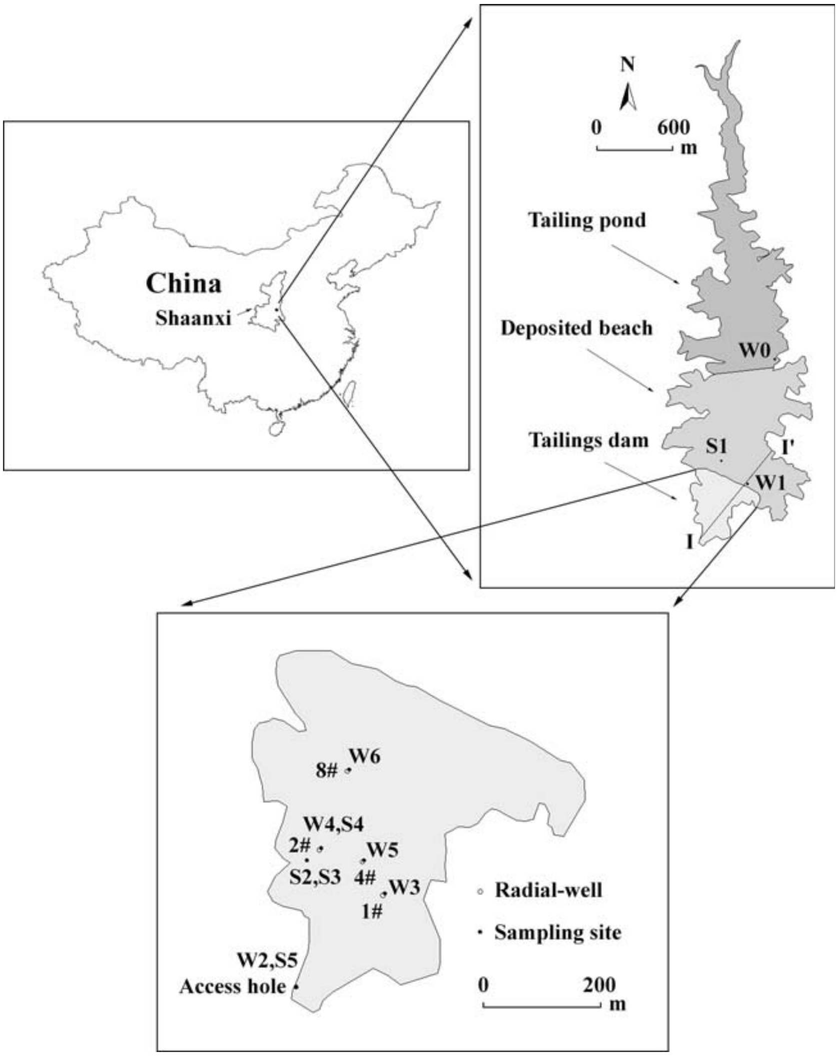


Fig. 1 Location map of the tailings dam and the sampling sites

the composition and species of the clogging materials in field investigations of Lixi tailings dam, and to use a continuous flow column to simulate clogging process of the tailings dam in the laboratory.

Materials and methods

Sampling

A field investigation was carried out in November 2005 as shown in Figs. 1 and 2. Solid samples were collected from the tailings dam body and the drainpipe. Water samples were collected from the discharge port of the radial collector wells. For the solid samples, a 10 cm × 10 cm section was excavated using a wooden shovel, and the samples were collected with a wooden spoon and stored in polyvinyl chloride (PVC) bags. Samples of slurry-like clogging materials (which were mainly distributed in the drainpipe) were collected with a wooden spoon and stored in PVC bottles.

Water samples from the discharge ports were collected and stored in PVC bottles before analysis. Seven water samples were collected, W0–W6. W0 was collected from the tailings pond, W1 from the tailings slurry that was influent to the tailings dam, W2 from the effluent of the access hole of the starter dam, and W3–W6 from the effluent of 1#, 2#, 4#, 8# radial-wells, respectively. Furthermore, water sample W1 was also filtered through a 0.45 μm membrane and stored for ICP-AES analysis.

Six solid samples were collected from the tailings dam, including two clogging samples. They were named S1–S6; S1 was collected from the deposited beach, S2 and S3 were collected from the dam body near the 2# radial-well, S4 and S5 were samples of clogging material from the 2# radial-well pipe and the access hole, respectively, and location of S6 was not

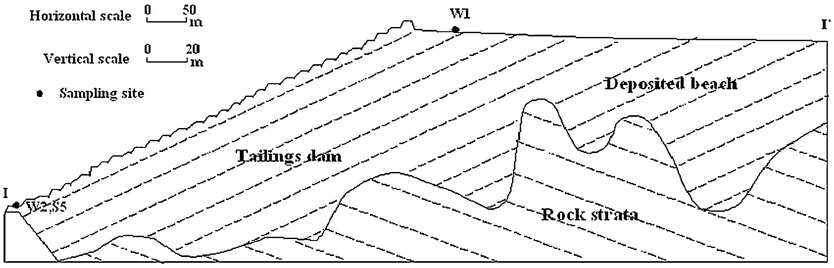


Fig. 2 Cross section along transect I–I′ in Fig. 1

shown in Fig. 1 because it was centrifugally separated from the tailings slurry that was collected from the same location of the W1.

Before analysis was carried out, solid and clogging samples were firstly air-dried at room temperature, ground in an agate mortar and passed through a sieve (mesh size 0.074 mm).

Experimental set-up and procedure

From observations made during fieldwork, it is hypothesized that reducing conditions in the tailings dam body promote the formation of ferrous ion; water flowing from radial-wells should therefore contain some ferrous ion. As the pH is relatively high (6.8–7.5), conditions are ideal for ferrous iron to be oxidized to ferric iron by dissolved oxygen. The resulting solid ferric hydroxide would form the clogging materials. Therefore, in the experiment, ferrous iron solution is set-up to flow through the experimental column to simulate formation of the clogging materials in the field.

The test solution was carefully prepared so as to maintain reducing conditions with the procedure that deionized water was firstly deoxygenated by the continuous bubbling of high-purity nitrogen for about 30 min. Whilst still under nitrogen bubbling, a predetermined amount of ferrous sulfate was added to reach the initial desired ferrous iron concentration. Finally, the test solution was pumped into the infusion bag to isolate the air. The test solution was re-prepared every 2 days. This procedure prevented oxidation of ferrous iron and maintained reducing conditions in the interior part of the column. The whole experiment was run continuously, and ferrous iron and total iron concentrations of the outlet water were monitored every day.

The column, 5 cm in diameter and 110 cm long, was packed with clean quartz sand ranging from 0.10 to 0.20 mm (a particle size similar to that in the tailings dam). The column had an inlet at the bottom and an outlet at the top. A peristaltic pump was used to inject the solution into the bottom inlet in order to maintain saturated conditions. The sand layer was 70 cm deep, and the distance between the top of the sand layer and the outlet was approximately 10 cm; this provided a ferrous iron solution layer so as to make formation of clogging materials easier. The water of the ferrous iron solution layer was maintained at the pH range 6.8–7.5 using a buffer solution so as to simulate natural tailings dam discharge.

During the experiment, the test solution was prepared with ferrous sulfate under the continuous bubbling of high-purity nitrogen, and was pumped using a peristaltic pump from the bottom to the top of the experimental column. The experiment was operated for 23 days, and was stopped when the outlet was completely clogged to result in increasing water levels and a clearly reduced flow rate.

Clogging sample SE1 was collected from the column and stored in a PVC bottle. Quartz sand samples were taken from different sections of sand layer of the column [SE2: 0–20 cm, SE3: 20–40 cm, SE4: 40–60 cm, and SE5: 60–70 cm, from the bottom (0 cm) to the top (70 cm) of the sand layer] and stored in PVC bags. Before chemical analysis, the sand samples and clogging samples were firstly air-dried at room temperature, ground in an agate mortar and passed through a sieve (mesh size 0.074 mm).

Chemical analysis

The water samples from the tailings dam were analyzed for the major ions Ca^{2+}, Na^{+}, SO_4^{2-}, CO_3^{2-}, HCO_3^{-}, Cl^{-}, Fe_{total} by adopting the standard method recommended by USEPA. Methylthymol blue flow injection analysis and mercuric thiocyanate flow injection analysis were adopted to analyze SO_4^{2-} and Cl^{-}, respectively. And the anions including CO_3^{2-} and HCO_3^{-} were analyzed by titration. Temperature, pH, conductivity, ORP and TDS were measured in situ by using an Ultrameter II™ 6P (Myron L Company, USA).

The solid and clogging samples from the tailings dam were subject to inductively coupled plasma atomic emission spectroscopy (ICP-AES). These samples were analyzed on an Iris Advantage 1000 (Thermo Jarrell Ash Corporation, USA).

Ferrous iron and total iron concentrations of the water samples from the laboratory experiment were measured using a Hach DR/2400 portable spectrophotometer (Hach Company, USA). The iron contents of the solid and clogging samples from the experiment were also analyzed using this device. Ferrous iron powder-pillows containing 1,10 phenanthroline and FerroVer reagent powder-pillows were used to measure ferrous iron and total iron, respectively. Other parameters such as temperature and pH were measured using the Ultrameter II^{TM} 6P (Myron L Company).

The solid and clogging samples from the tailings dam and laboratory experiment were also characterized using X-ray powder diffraction (XRD). X-ray analyses were performed by D8 ADVANCE X-ray polycrystalline diffractometer (Bruker axs GmbH, Karlsruhe, Germany). X-ray analyses used Cu Kα radiation ($\lambda = 1.5406$ Å), with a graphite filter and a position sensitive detector (PSD). XRD was operated at 40 kV and 40 mA. The scattered intensities were measured with a NaI dynamic scintillation counter. Scans were run from 10° to 90° (2θ), with a step size of 0.02°.

The surface morphology of the clogging samples from the tailings dam and laboratory experiment was determined with a Field Emission Scanning Electron Microscope. Micrographs were taken by a FEI SIRION 200 SEM (FEI Company, USA). An accelerating voltage of 5 kV was used during the procedure, with a resolution of 3 nm. The clogging sample was prepared with gold coating to increase its electrical conductivity. The element analysis of the clogging sample surface was determined by EDS (energy dispersive spectrometer). An OXFORD INCA EDS (OXFORD Instruments, UK) was employed during analysis.

Results and discussion

Water quality of the tailings dam

Seven water samples were collected, W0–W6. The elevation of the radial-wells increases with increasing well number. Table 1 lists the physical and chemical data from unfiltered water samples, analyzed either in situ or in the laboratory. Table 2 shows the results of element analysis for sample W1 after filtration.

Table 1 and Fig. 3 show that the water types of these samples are SO_4^{2-}–Ca^{2+} and $SO_4^{2-}HCO_3^-$–Ca^{2+}. Almost all anion and cation concentrations for the tailings pond water (W0) are relatively lower than those of the inflowing tailings slurry (W1) and the water samples from the radial-wells (W3, W4, W5 and W6). The water from different wells has a similar composition. The pH range 6.8–7.5 means the likelihood of forming ferrous iron is relatively low. Under these conditions, the ferrous iron oxidation rate is sufficient to allow the ferrous iron present to be oxidized into ferric iron. Unfortunately, dissolved oxygen (DO) was not measured due to failure of the apparatus; less ferrous iron will be present only if DO is sufficient. Table 1 shows that almost all the Fe_{Total} concentrations in the unfiltered waters are lower than 1.6 mg/L. It is assumed

Table 1 Water quality parameters of unfiltered water samples

Parameter	W0	W1	W2	W3	W4	W5	W6
T (°C)	11.4	14.4	12.3	12.3	11.5	11.5	11.5
pH	6.8	7.18	7.29	7.39	7.14	7.44	6.87
EC (μS/cm)	1,028	1,116	1,102	1,136	1,228	1,266	1,348
ORP (mV)	188	140	–68	–83	–70	–93	–33
TDS (ppm)	725.2	788.2	781.3	805.7	876.4	905.8	965.1
$K^+ + Na^+$(mg/L)	74.8	110.8	68.6	74.9	86.7	84.3	108.6
Ca^{2+}(mg/L)	139.3	146.5	146.3	154.3	164.3	182.4	184.4
Mg^{2+}(mg/L)	9.7	14.6	20.7	14.6	17.6	17	15.8
Fe_{Total} (mg/L)	<0.080	1.15	0.359	0.807	0.598	1.595	0.5
Cl^- (mg/L)	12.4	10.6	10.6	23	14.2	12.4	12.4
SO_4^{2-} (mg/L)	444.3	518.7	437.1	458.7	530.7	547.5	605.2
HCO_3^- (mg/L)	85.4	58	158.6	122	122	152.5	140.3

Note: CO_3^{2-} was not detected

Table 2 Chemical composition of the inflowing tailings slurry in ppm

Al	B	Be	Ca	K	Mg	Mn	Mo	Na	S	Si	Sr	Zn
0.47	0.11	0.16	146.5	29.84	14.58	0.43	2.3	80.98	172.9	0.78	12.85	0.007

Note: Fe was not detected for the filtered water sample (W1)

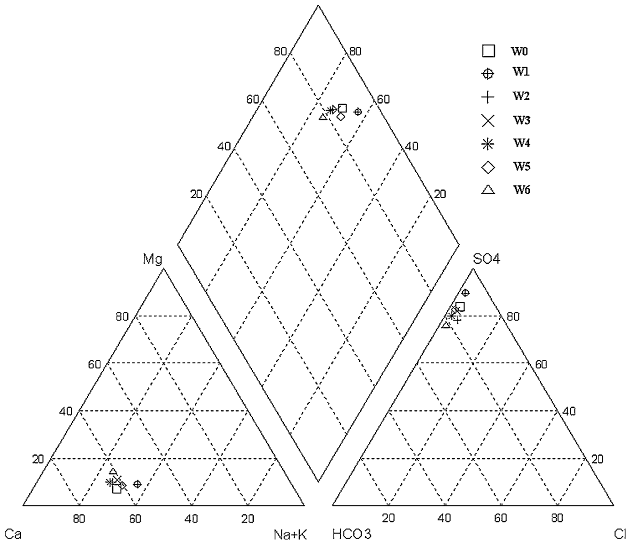


Fig. 3 Piper diagram

that considerable proportion of Fe exists in the water as a precipitate, suspended solid or colloid. The results of Table 2 show that Fe was not detected in the ICP analysis of the filtered sample (W1).

Chemical composition of solids and the clogging materials

Six solid samples were collected from the tailings dam, including two clogging samples. Sample S2 and S3 were collected from a similar location, although the samples were in different colors; S2 was red, and S3 was yellow and located deeper in the sediment. S4 and S5 were reddish brown and mud-like, and S1 and S6 were gray in color.

Table 3 lists the chemical composition of the six samples. The results from the ICP-AES analysis indicate that the solid samples S1 and S6 have similar chemical compositions, with low iron content when compared with the other samples. ICP-AES results indicate that S2 have more iron than S3. Also S2 and S3 have a similar composition in which iron is the most representative element, however S2 shows a Fe concentration higher than S3. The solid samples S1 and S6 had the similar XRD spectra, so the spectrum of S1 was selected to illustrate the species. In the same way, solid sample S2 and S3 had the similar XRD spectra, so S2 was selected as representation. Figure 4a, b shows XRD spectra of samples S1 and S2, respectively. Only goethite (α-FeOOH) could be detected in these samples. This suggests that iron compounds, which have relatively good crystallographic forms in the dam body, might exist as FeOOH. Samples S4 and S5 are clogging materials, show a similar composition, and iron is the dominant element with a content of 54.35 and 40.24% for S4 and S5, respectively. These data are enough to prove that the clogging materials are mainly composed of iron compounds. The contents of other elements such as Ca, Mg, Mn, Mo, Zn, and Ti are found to be low to form the main clogging matter. The XRD spectra of clogging samples S4 and S5 are given in Fig. 5a, b, respectively. It is hypothesized that the presence of some amorphous materials would make it difficult to detect more iron compounds in detail. Only the most dominant species with relatively good crystallographic form can be detected and analyzed. Figure 5 shows that the XRD spectrum of S4 (collected from the 2# radial-well) is different from that of S5 (collected from the access hole of the starter dam and at a lower elevation). Figure 5a shows that goethite (α-FeOOH) and ferric hydroxide ($Fe(OH)_3$) are the main components in sample S4. Figure 5b shows that akaganeite (β-FeOOH) and hematite (α-Fe_2O_3) are the main components for sample S5. From Fig. 5a, b we can deduce that although some differences may exist between clogging samples, the main components are essentially the same. It is assumed that ferric hydroxide ($Fe(OH)_3$) is the main initial component for the clogging materials. Other compounds such as akaganeite (β-FeOOH), hematite (α-Fe_2O_3) and goethite (α-FeOOH) can be transformed from ferric hydroxide ($Fe(OH)_3$). The SEM micrographs of sample S4 (Fig. 6) show the microstructure of sample S4 at different scales. EDS is used to analyze the chemical composition of the surface of the clogging material S4, and the results are shown in Table 4 and Fig. 7. The results indicate

Table 3 Chemical composition of solid samples collected from the tailings dam

Element	S1	S2	S3	S4	S5	S6
Ca	2.379	0.4945	0.5987	0.9416	1.98	2.916
Cu	0.015	0.0201	0.0153	–	0.0054	0.0158
Fe	4.724	17.72	13.84	54.35	40.24	6.121
Mg	1.548	0.9838	0.3676	0.0493	0.5614	1.981
Mn	0.1446	0.0645	0.0419	0.2335	0.3195	0.179
Mo	0.057	0.0708	0.1004	0.5762	0.1654	0.0233
Ti	0.2914	0.3117	0.3621	–	0.081	0.3682
Zn	0.0284	0.0161	0.0092	0.049	0.0308	0.0311

Unit: wt. %

Note: "–" Not detected

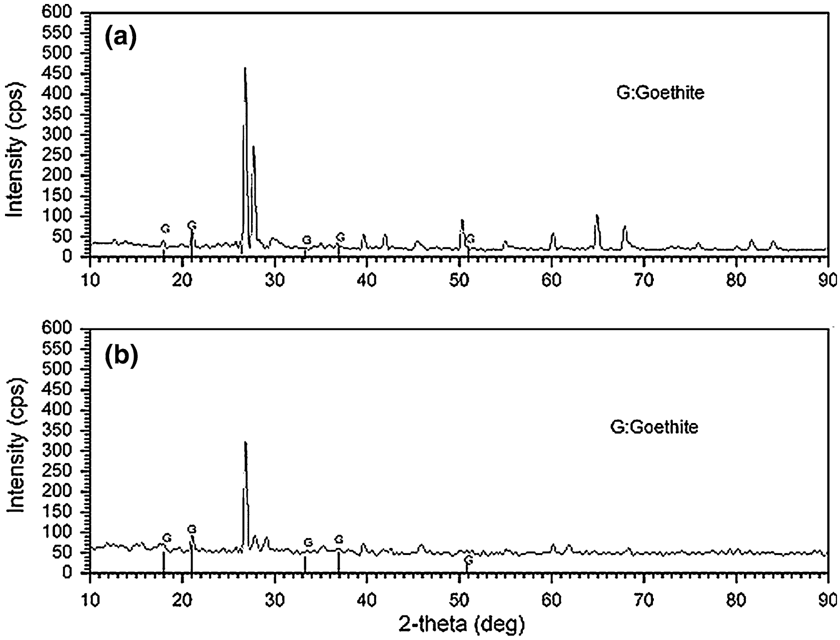


Fig. 4 Iron compounds in the solid materials collected from the tailings dam analyzed by XRD

that iron is the dominant element present in the surface and oxygen is the second most common element. It further proves that ferric hydroxide is possibly the main component of the clogging materials and the structure of ferric hydroxide in the clogging materials is loose without good crystallographic form.

Clogging experiment

At the beginning of the clogging experiment, a change in color of the water layer occurred to a considerable extent. At first, the sand layer was saturated by the test solution without adjusting the pH of the water layer, which was colorless. Then, the buffer solution was added to adjust the pH of the water layer that then changed to yellow-brown, indicating oxidation of ferrous iron to ferric iron. During the procedure, reddish-brown precipitates formed and were gradually deposited on the surface of the sand layer. At the same time, the water layer became turbid and some precipitates adhered to the interior wall of the column and the outlet. During the following stages of the operation, it became more difficult to observe the clogging materials

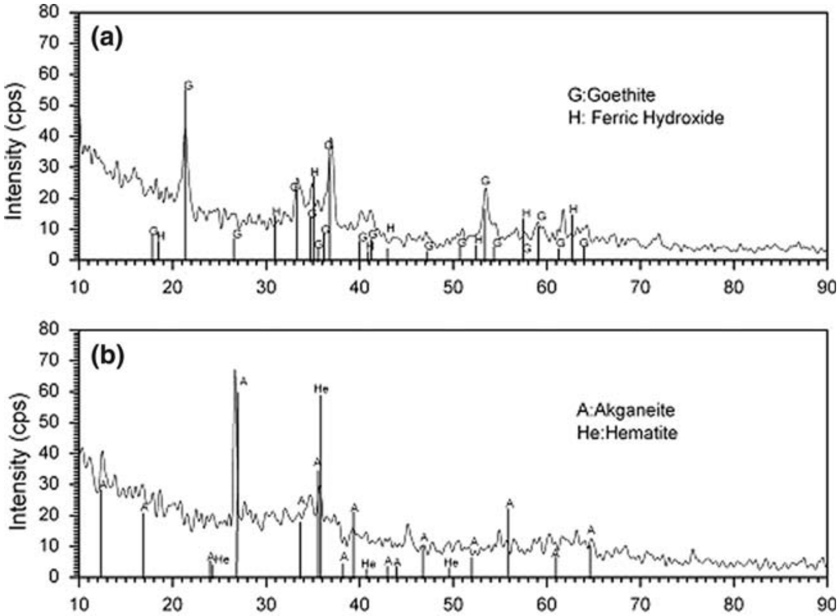


Fig. 5 Iron compounds in the clogging materials collected from the tailings dam analyzed by XRD

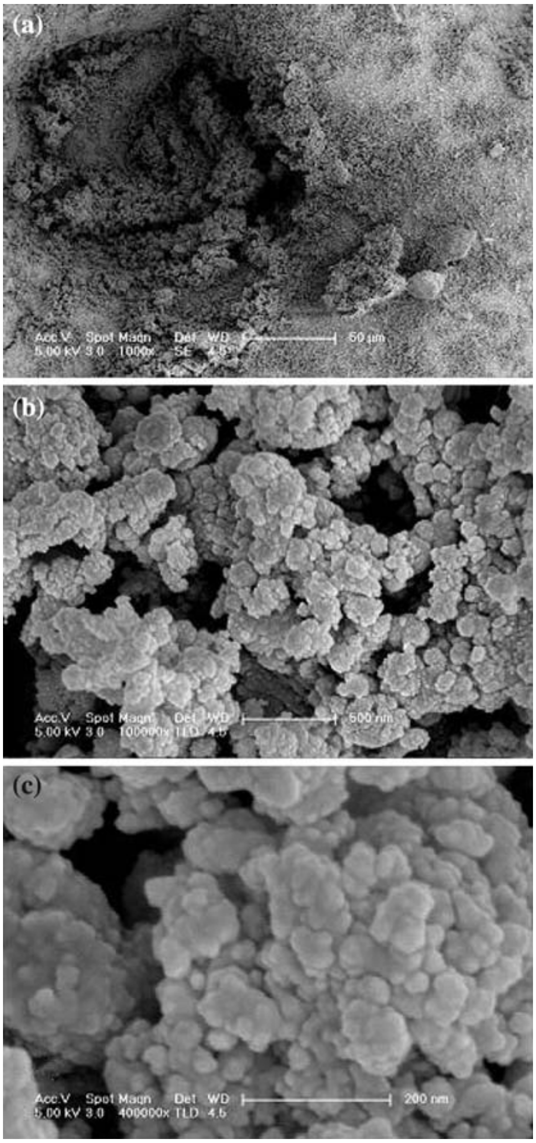


Fig. 6 SEM micrographs of the clogging sample S4

Table 4 EDS results of the clogging sample S4 collected from the tailings dam

Element	Weight %
C	15.37
O	28.81
Si	3.93
Ca	2.21
Fe	49.67

through the transparent column wall because it had been covered with a thin layer of reddish-brown material. The thickness of the clogging layer gradually increased and the walls of the outlet were completely covered by the reddish brown precipitates.

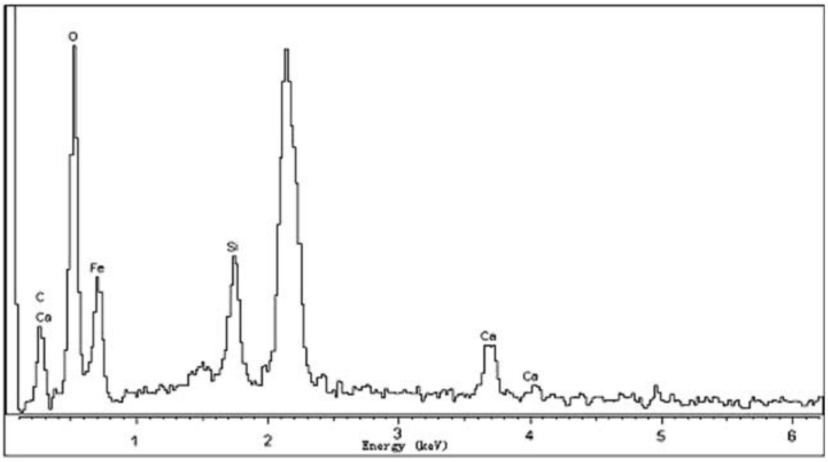
To simulate clogging in the laboratory and to make the clogging form more easily and more significantly, a relatively high concentration (100 mg/L) of ferrous iron was employed at the inlet. After nitrogen bubbling, the test solution contained little oxygen, which allowed maintenance of reducing conditions and restricted the formation of precipitates in the interior part of the column. The ferrous iron concentrations of different sections of the column were monitored regularly. Ferrous iron concentrations of these sections (0–20, 20–40, and 40–60 cm) were about 99 mg/L, which indicated that reducing conditions were maintained and little iron was precipitated in the interior part of the column.

During the experiment, ferrous iron and total iron concentrations were monitored every day at the outlet. Figure 8 shows the changes in concentration with time. The dissolved oxygen of the water layer sometimes might be insufficient because oxygen in the water was provided by the air. But during the everyday operation, oxygen mass transfer and ferrous iron oxidation could reach equilibrium state. Some ferrous iron was oxidized to ferric iron forming precipitates. The rest flowed through the column and had no impact on the clogging materials. Total iron in the water layer was composed of two parts, one part was residual ferrous iron and the other part was ferric iron. Some total iron formed precipitates on the surface of the sand layer, on the wall of the column or on the outlet. The rest of the total iron flowed through the column. During the whole operation, the concentrations of ferrous iron and total iron varied within a relatively stable range, 20–60 and 30–80 mg/L, respectively. This indicated that ferrous iron oxidation and precipitation could reach equilibrium under the conditions of the stable pH and the natural oxygen supply.

When the column was clogged, a clogging sample SE1 and four solid samples from different sections of the column (SE2: 0–20 cm, SE3: 20–40 cm, SE4: 40–60 cm, and SE5: 60–70 cm) were collected and analyzed. The iron content of each sample was measured, and results were presented in Table 5.

The iron content of the clogging sample is high, 64.90%, when expressed as a percentage of Fe_2O_3, or 86.80% if expressed as a percentage of $Fe(OH)_3$. The clogging materials are mainly iron compounds, similar to the field investigation. The iron contents of the solid samples are fairly small, indicating that the interior part of the column maintains reducing conditions, preventing oxidation of ferrous iron. XRD spectrum of the clogging sample is given in Fig. 9. Absence of obvious peaks in Fig. 9 means that the clogging material is presented as an amorphous state. Hematite (α-Fe_2O_3) was detectable by XRD. According to the results of the field investigation, ferric hydroxide ($Fe(OH)_3$), goethite (α-FeOOH), akaganeite (β-FeO-

Fig. 7 EDS results of the clogging sample S4



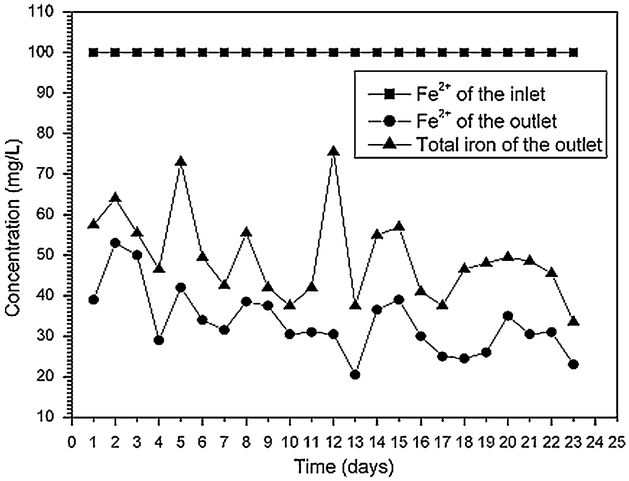


Fig. 8 Evolution of ferrous iron and total iron of the column outlet

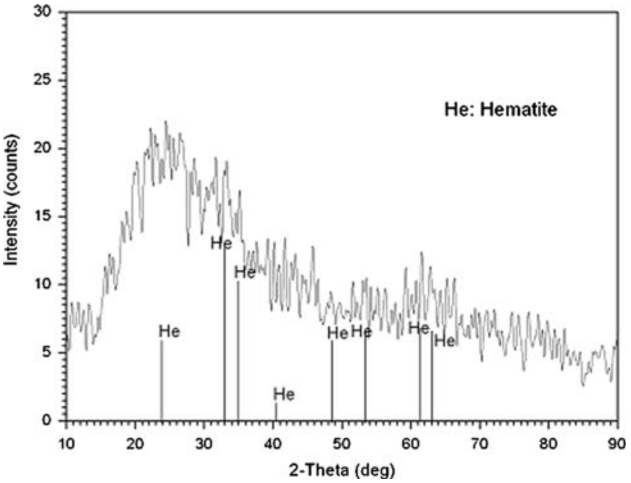


Fig. 9 Iron compounds in the clogging sample SE1 collected from the sand column analyzed by XRD

Table 5 Iron content of the clogging and solid samples collected from the sand column

	SE1	SE2	SE3	SE4	SE5
Fe (Weight %)	45.43	0.2060	0.3201	0.2999	0.2398

OH) and hematite (α-Fe_2O_3) were the main components for the clogging materials. The ferric hydroxide ($Fe(OH)_3$) should be the main initial component for the clogging materials. The other compounds such as akaganeite (β-FeOOH), hematite (α-Fe_2O_3) and goethite (α-FeOOH) are the products from ferric hydroxide ($Fe(OH)_3$). The presence hematite (α-Fe_2O_3) detected in this work proved the hypothesis put forward in the field investigation that ferric hydroxide ($Fe(OH)_3$) was the main component and could transform into hematite (α-Fe_2O_3). FeOOH was not detected, perhaps because clogging materials in situ had a longer period of possible transformation from ferric hydroxide ($Fe(OH)_3$) to FeOOH. In contrast, the laboratory experiment was only operated for 23 days when clogging occurred. It could therefore be concluded that the clogging materials mainly existed in an amorphous state. Figure 10a–c shows the microstructure of a clogging sample from the laboratory column at different scales. EDS results for the laboratory clogging sample are shown in Table 6 and Fig. 11. Iron (47.61%) and oxygen (44.91%) are the most common elements for this sample. It further proves that ferric hydroxide is possibly main composition for the clogging materials and the structure of ferric hydroxide in the clogging materials generated experimentally is loose without good crystallographic form.

Clogging mechanism

The solid samples and clogging samples have different iron contents, and the iron contents for the two

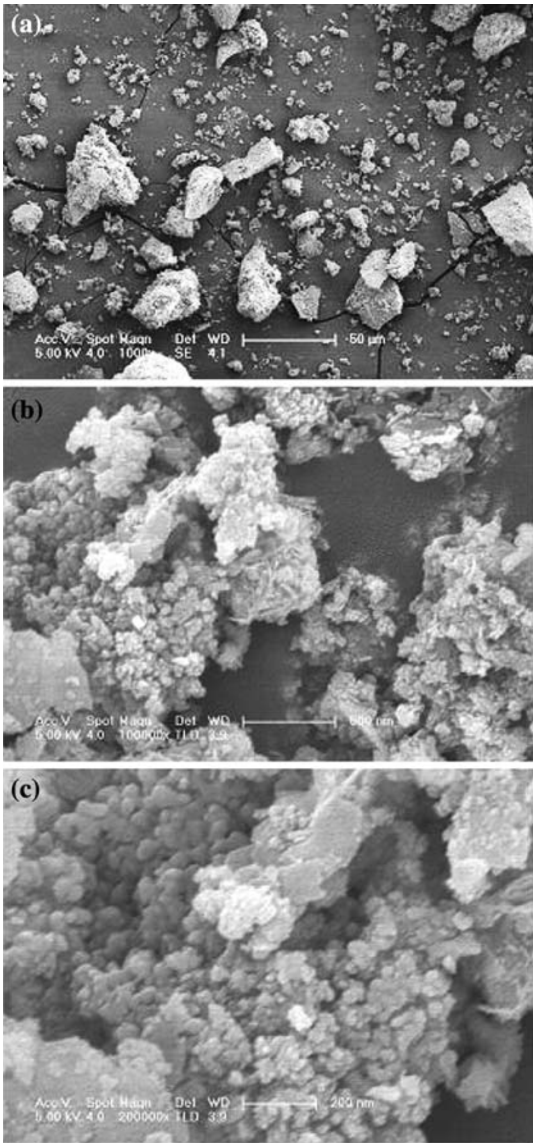


Fig. 10 SEM micrographs of the clogging sample SE1 collected from the sand column

clogging materials are over 40%. This suggests that the clogging materials are mainly composed of iron compounds, especially ferric hydroxide ($Fe(OH)_3$). Other crystallographic forms such as goethite (α-FeOOH), Akaganeite (β-FeOOH) and Hematite (α-Fe_2O_3) are also detected. It seems likely that these compounds are transformed from ferric hydroxide ($Fe(OH)_3$). The mechanism of the formation of the clogging materials can be explained as follows. Firstly, the reducing condition of the interior dam body easily makes ferrous ion form, so water from the radial-wells should contain some ferrous ion.

Conditions of the high pH range 6.8–7.5 are ideal for ferrous iron to be oxidized to ferric iron with dissolved oxygen in the water:

Table 6 EDS results of the clogging sample SE1 collected from the sand column

Element	Weight %
O	44.91
Si	7.48
Fe	47.61

$$2Fe^{2+} + \frac{1}{2}O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O.$$

Solid ferric hydroxide is then formed:

$$Fe^{3+} + 3OH^- \rightleftarrows Fe(OH)_3.$$

Ferric hydroxide can transform into other iron compounds:

$$2Fe(OH)_3 \rightarrow Fe_2O_3 + 3H_2O.$$

$$Fe(OH)_3 \rightarrow FeOOH + H_2O.$$

When these materials gradually accumulate, the pore in the tailings dam and the sand column will be clogged.

Conclusions

Chemical analysis of clogging materials collected from the tailings dam shows that the dominant element is Fe: 54.35% (from 2# radial-well pipe) and 40.24% (from the access hole of the starter dam). XRD semi-qualitative analysis indicates that the percentage of $Fe(OH)_3$ and α-FeOOH in sample S4 is 57.2 and 42.8%, respectively, and the percentage of Fe_2O_3 and β-FeOOH in sample S5 is 94.3 and 5.7%, respectively.

To simulate the clogging, a laboratory experiment was carried out. The experiment was finished after 23 days because the outlet of the column was clogged, with a resulting increase in water levels. The dominant element in the clogging materials is Fe: 45.43%.

XRD spectra indicate some differences between samples S4 and S5. However, the main component of both materials is ferric hydroxide that can transform into other iron compounds such as akaganeite, hematite and goethite. The lack of obvious peaks in the XRD spectrum of the clogging sample means that the material is amorphous. Hematite is the only iron compound detected by XRD for the clogging sample collected from the sand column. It is hypothesized that ferric hydroxide should be the main component because it can transform into hematite. The above results clearly show that the clogging materials are mainly composed of iron compounds.

The mechanism for formation of the clogging materials is that ferrous ion, under reducing conditions

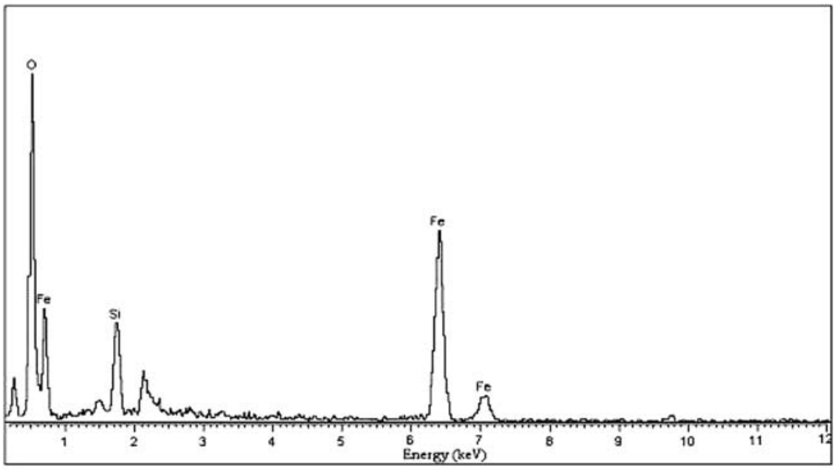


Fig. 11 EDS results of the clogging sample SE1 collected from the sand column

within the interior dam body, is oxidized to ferric ion by dissolved oxygen, forming ferric hydroxide which can precipitate and gradually accumulate in the radial-well pipes. Ferric hydroxide can gradually dehydrate and slowly change into Fe_2O_3 and another Fe (III) oxide–FeOOH which has different crystallographic forms such as goethite and akaganeite. Therefore the clogging materials are a mixture of ferric hydroxide and its converted products. The clogging materials from the tailings dam and experiment exist in an amorphous form with a cluster microstructure.

Clogging is one of the most important factors affecting the stability of the tailings dams. Therefore, enhancing iron separating will be useful for decreasing iron content of the tailings and occurrence of clogging.

Acknowledgments This work is financially supported by the National Foundation of Science of China (No. 10572090). The authors would like to thank Instrumental Analysis Center of Shanghai Jiao Tong University for making XRD, ICP-AES and SEM-EDS facilities available to us. The authors wish to thank Zhenshi Guo and other people of JMGMC for their help during the fieldwork. The authors also wish to thank the anonymous reviewers for their reading of the manuscript, and for their suggestions and critical comments.

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