

CHAPTER IV

TEST RESULTS AND DISCUSSION

4.1 General

The results and discussion on the experiments are summarized in five aspects for each media as follows:

- Leachability of heavy metals
- Chemical and physical properties of iron filing, bentonites, coal dust and spent foundry sands
- Results of batch sorption tests for iron filing, bentonites and coal dust
- Results of batch sorption tests for spent foundry sands
- Comparison between spent foundry sand and synthetic sand

4.2 Leachability of heavy metals

The environmental stability of spent foundry sand has been shown very clearly by a number of investigations (CEERE 2000 and Lee et al. 2004). Different procedures for evaluation of leachability of chemicals exist (USEPA SW 846). The hazardous waste characteristics promulgated by Thai Ministry of Industry designate broad classes of wastes with inherent properties which can be harmful to health or the environment if mismanaged.

The leachate extraction procedure outlined in the 6th Notification of the Ministry of Industry (1997) is designed to measure the potential for toxic constituents in the waste to leach out and contaminate groundwater. The leachability of heavy

metals from each foundry sands and the comparison with regulatory standard are shown in Table 4.1.

Table 4.1 Compare the results with regulatory standard

Metal	Sand 1 (mg/l)	Sand 2 (mg/l)	Sand 3 (mg/l)	Sand 4 (mg/l)	Standard ¹ (mg/l)
As	< 0.05	< 0.05	< 0.05	< 0.05	5
Ba	1.451	0.511	0.682	0.494	100
Cd	0.025	<0.005	<0.005	<0.005	1
Cr	1.442	0.004	< 0.007	<0.007	5
Pb	< 0.050	< 0.050	< 0.050	< 0.050	5
Hg	< 0.040	< 0.040	< 0.040	< 0.040	0.2
Se	< 0.050	< 0.050	< 0.050	< 0.050	1
Ag	< 0.007	< 0.007	< 0.007	< 0.007	5

¹ The regulatory standard of leachate extraction procedure outlined in the 6th Notification of the Ministry of Industry (1997)

Several conclusions can be drawn from the existing data. There are small amount of heavy metals contained in leachate from each waste foundry sands. In addition, Ba, Cd, and Cr were found in leachate from Sand 1. Both Ba and Cr were also found in leachate from Sand 2 whereas only Ba was found in leachate from Sand 3 and Sand 4. However, waste foundry sands leachate metal contents were well below the standard. This is usually because the constituents are either present in forms that are not soluble or are unavailable to the leaching medium. As a result, waste foundry sands are non-hazardous waste.

4.3 Chemical and physical properties of iron filing, bentonites, coal dust and spent foundry sands

4.3.1 Iron filing

Commercially available iron filing granular was used as a zero valence iron, which is one of sorbents for these serial experiments. The purity of the iron is 79.55 % by weight. The mean particle size was 0.106 mm. The Particle size distribution curves for iron filing are shown in Figure 4.1.

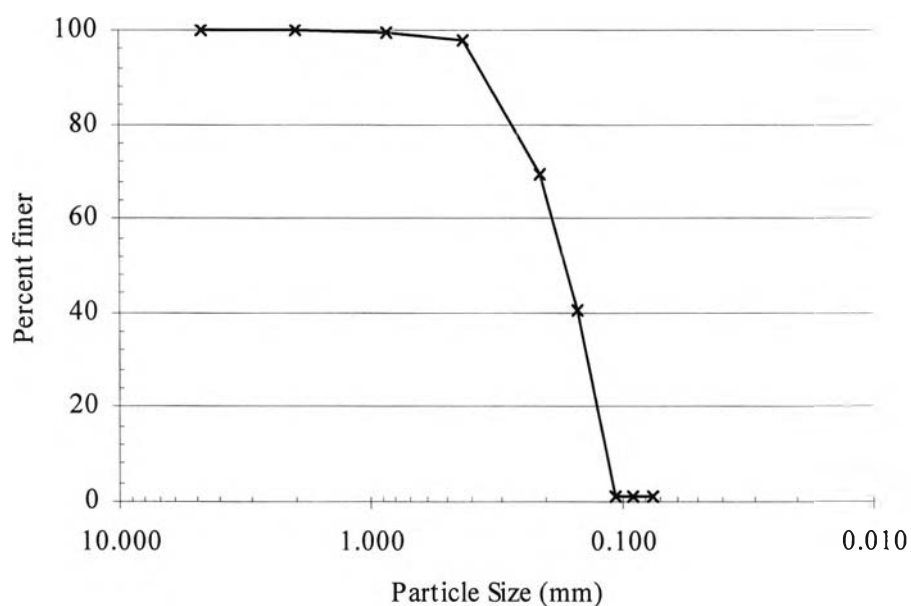


Figure 4.1 Particle size distribution curves for iron filing

4.3.2 Bentonites

Two calcium bentonites were obtained from Sud-Chemie and Thai Nippon Chemical Industry Co., Ltd. These bentonites were also used for comparative test. The particle size distribution curves for bentonites are presented in Figure 4.2.

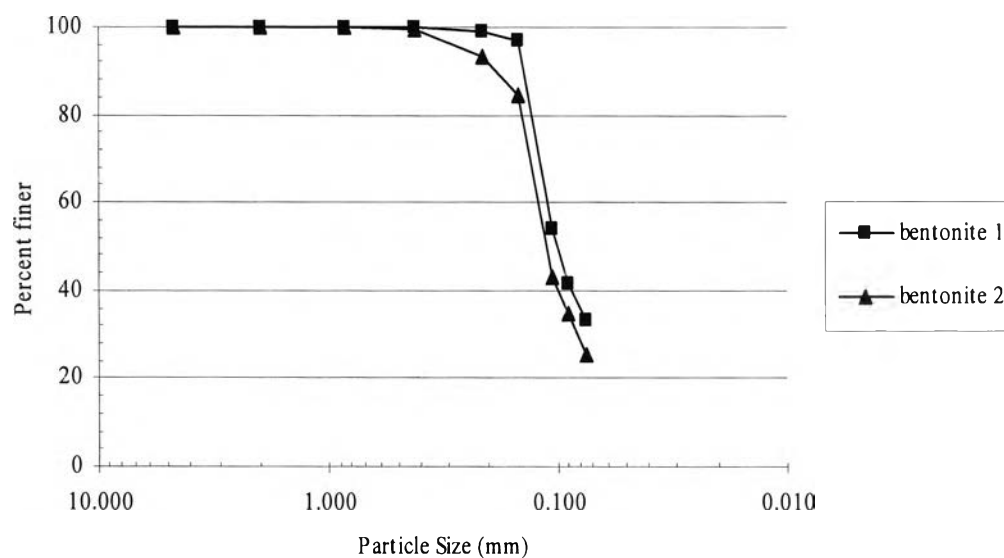


Figure 4.2 Particle size distribution curves for bentonites

The physical properties of these bentonites given by Sud-Chemie and Thai Nippon Chemical Industry Co., Ltd. are summarized in Table 4.2. The montmorillonite content of Bentonite 1 and Bentonite 2 are 82% and 76.3%, respectively.

Table 4.2 Physical properties of bentonites (Sud-Chemie and Thai Nippon Chemical Industry Co., Ltd.)

Typical physical properties	Bentonite 1	Bentonite 2
1. Moisture Content, %	9.90	11.6
2. pH	10.18	9.9
3. Swelling Index, ml/2g	13	20
4. Montmorillonite Content, %	82	76.3
5. Dry Particle Pass 200 Mesh, %	77.30	81.1
6. Compression Strength, N/cm ²	15.74	10.8

Chemical composition

Chemical compositions of bentonites were determined by X-ray Fluorescence Spectrometry. The chemical compositions for bentonite 1 and bentonite 2 are summarized in Table 4.3.

Table 4.3 Chemical composition of bentonite1 and bentonite 2

Constituent	Bentonite 1 (% by weight)	Bentonite 2 (% by weight)
SiO ₂	57.6	54.3
Al ₂ O ₃	19.8	27.1
Fe ₂ O ₃	3.2	4.1
Na ₂ O	1.6	1.4
CaO	3.1	1.8
MgO	2.9	3.9
Loss On Ignition (LOI)	11.8	7.4

4.3.3 Coal dust

In this study, coal dust was sourced of organic carbon, a significant index parameter. The coal dust that used in these experiments was obtained from Mae-Moh plant. Its chemical composition is presented in Table 4.4.

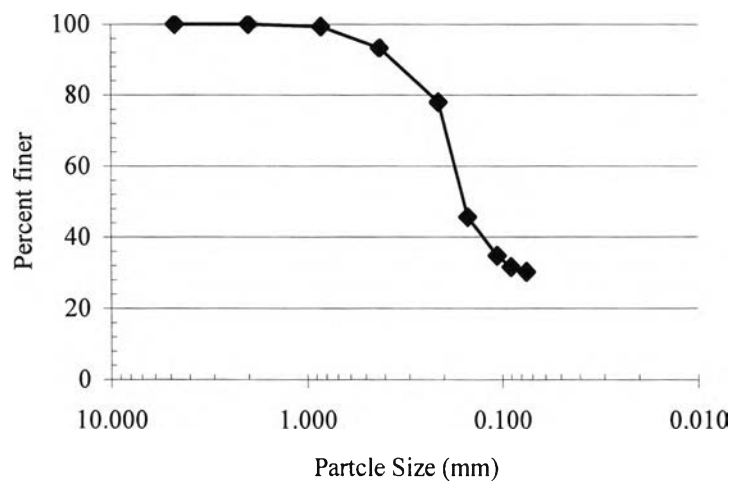


Figure 4.3 Particle size distribution curves for coal dust

Chemical composition

Chemical compositions of coal dust were determined by X-ray Fluorescence Spectrometry. The chemical compositions for coal dust are summarized in Table 4.4.

Table 4.4 Chemical compositions of coal dust

Constituent	% by weight
SiO ₂	59.3
Al ₂ O ₃	32.4
Fe ₂ O ₃	4.1
CaO	2.9
Loss On Ignition (LOI)	1.3

4.3.4 Spent foundry sands

Four spent foundry sands were used in this study. The spent foundry sands were obtained from foundries in Saraburi, Thailand. Particle size distribution curves for spent foundry sands are shown in Figure 4.4.

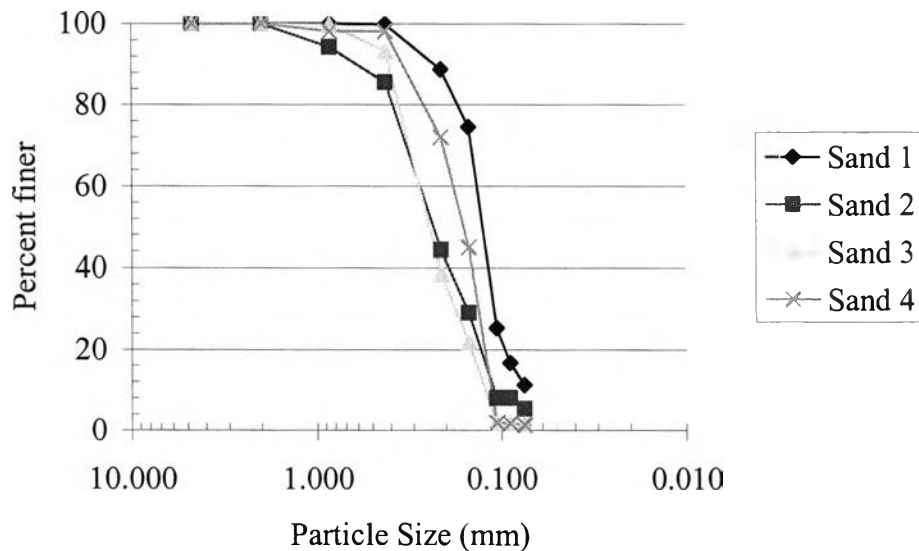


Figure 4.4 Particle size distribution curves for spent foundry sands

Physical properties of the green sands are summarized in Table 4.5. These sands contain a small clay fraction used as a binder in foundry molding processes. The percent of fine (fraction passing the US no. 200 sieve, 75 μ m) ranges from 1.35% (Sand 4) to 11.28% (Sand 1), the clay fraction ranges from 0% (Sand 4) to 19.14% (Sand1), and the specific gravity of solids ranges from 1.87 (Sand 4) to 2.56 (Sand3). The total organic carbon (TOC) ranges from 0.47% (Sand 4) to 2.03% (Sand 1), and the total iron content of waste sand ranges from 0% (Sand 4) to 4.46% (Sand 3).

Table 4.5 Physical properties of the spent foundry sands

Sample	Particle Size Characteristics		Clay content (%)	Specific gravity	Total Iron Content (%)	% TOC
	d ₅₀	Percent fine				
Sand 1	0.106	11.28	19.14	2.41	4.37	2.03
Sand 2	0.212	5.34	10.84	2.40	0.48	1.82
Sand 3	0.212	1.56	1.44	2.56	4.46	1.17
Sand 4	0.106	1.35	0.00	1.87	0.00	0.47

Chemical composition

Chemical compositions of spent foundry sands were determined by X-ray Fluorescence Spectrometry. The chemical compositions for foundry sands are shown in Table 4.6.

Table 4.6 Chemical compositions of raw mill and spent foundry sands

Chemical Composition (% by weight)	Sand 1	Sand 2	Sand 3	Sand 4
SiO ₂	70.8	92.5	77.8	97.5
Al ₂ O ₃	10.6	3.19	7.45	0.57
Fe ₂ O ₃	7.43	0.81	7.57	0.00
CaO	2.82	0.55	1.83	0.15
MgO	2.11	0.44	1.14	0.00
SO ₃	0.49	0.26	1.05	0.00
Na ₂ O	2.77	0.00	1.36	0.00
K ₂ O	0.95	0.88	0.52	0.11
TiO ₂	1.02	0.00	0.14	0.12
P ₂ O ₅	0.21	0.00	0.00	0.00
Loss On Ignition (LOI)	6.34	1.37	1.14	1.55

Primarily silicon dioxide (SiO_2) is a major component of spent foundry sands which vary in range of 70.8 – 97.5%. The iron oxides of each waste foundry sands vary in range of 0-7.57%.

4.4 Results of batch sorption tests using iron filing, bentonites and coal dust

4.4.1 Results of batch kinetic tests

Batch kinetic tests were conducted to determine the sorption kinetics of each media. In this part, iron filing, bentonites and coal dust were used.

A 2 g of iron filing, bentonites and coal dust were placed in 50 ml centrifuging Teflon[®] bottles containing 50 mg/l of zinc solution. Then, the bottles were shaken for various reaction times and concentrations were measured at designated sampling interval. The experimental conditions are shown in Table 4.7. Groundwater contaminated with zinc was synthesized for experiments in laboratory scale by dissolving zinc chloride in DI water to yield an expected zinc concentration of 50 mg/l and mixed with sodium azide (0.1% by weight) to prevent biological activity. Three different solutions pH (3.72, 6.59 and 8.01) were selected as initial pH according to typical range commonly found for groundwater. No pH buffer was used. The initial solution pH was adjusted with either 1.0 M of reagent grade nitric acid or sodium hydroxide.

Table 4.7 Experiment conditions for batch sorption tests using iron filing, bentonites and coal dust for zinc removal

Media	Mass of media (g)	Clay (%)	Iron Content (%)	TOC (%)
Bentonite 1	2	82.00	Not Applicable	0.24
Bentonite 2	2	76.30	Not Applicable	0.14
Iron Filing	2	Not Applicable	79.55	Not Applicable
Coal dust	2	Not Applicable	Not Applicable	Not Applicable

The zinc concentration decreased as time increased for iron filing, bentonites and coal dust for all pH of solutions. The equilibrium concentrations were found within 24 hours. Typical results are shown in Figures 4.5 – 4.7 (a). The decreases in concentration were high when the pH was high.

Figure 4.5 – 4.7 (b) show the results of solution pH as a function of contact time. The results show that the solution pH continued to increase as time progressed for all iron filing, bentonites and coal dust. The solution pH also stabilized within 24 hours which may indicate equilibrium.

The increasing pH of solutions resulted from buffering reactions. For iron filing, the corrosion of iron generates the hydroxyl group which elevates the pH of solution. The buffering probably caused by exchangeable base cations, and decomposition of aluminosilicate minerals may attribute increasing of solution pH for bentonites and coal dust (McBride, 1994).

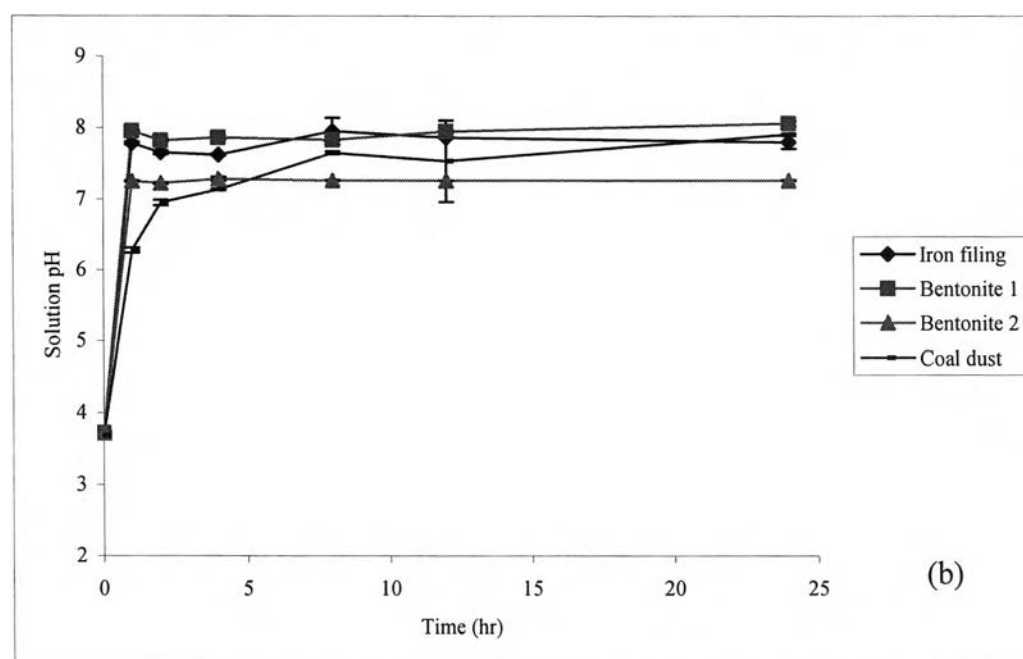
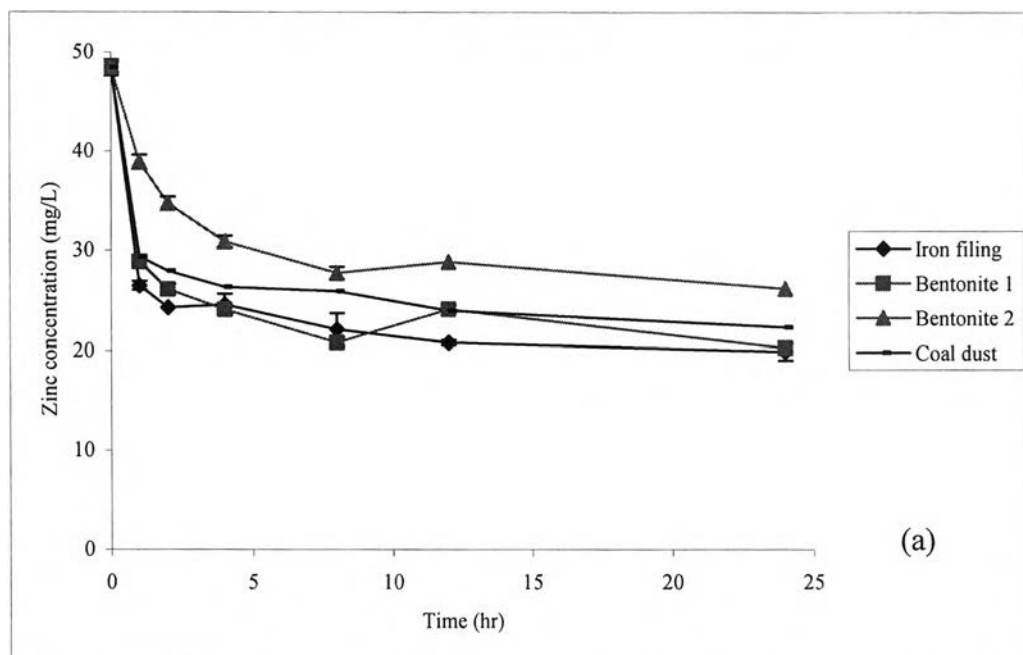


Figure 4.5 Results of batch kinetic tests for iron filing, bentonite 1, bentonite 2 and coal dust at initial pH 3.72: (a) Zinc concentration and (b) Solution pH

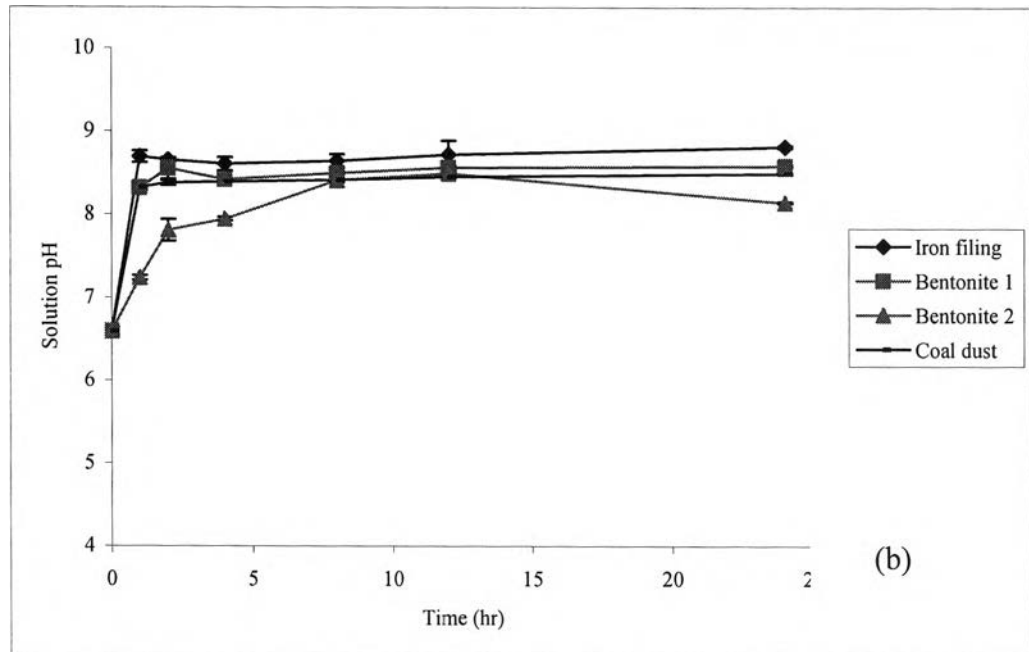
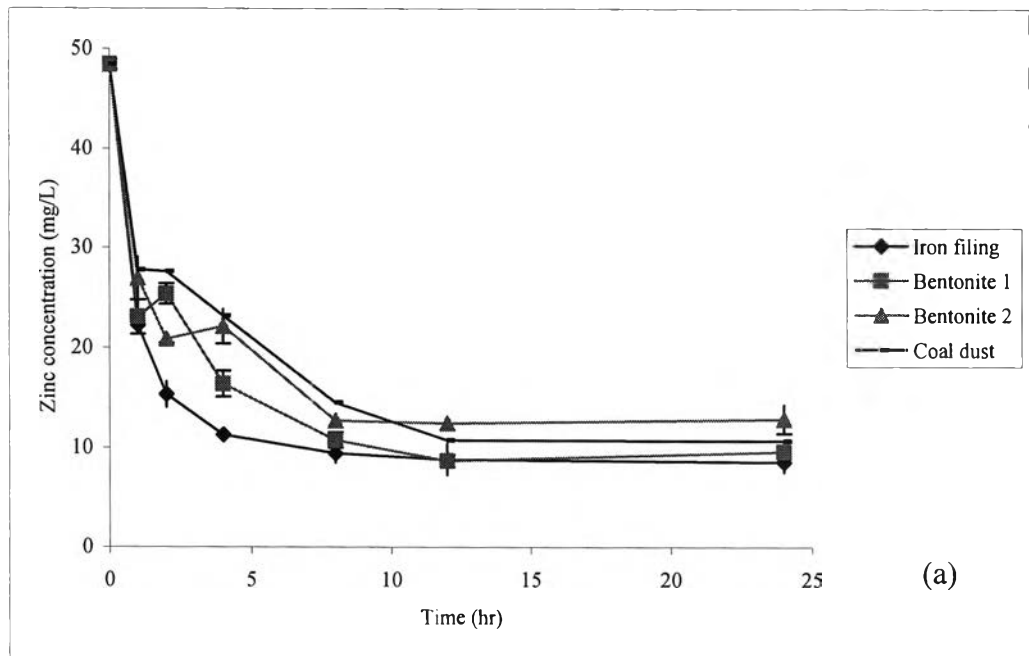


Figure 4.6 Results of batch kinetic tests for iron filing, bentonite 1, bentonite 2 and coal dust at initial pH 6.59: (a) Zinc concentration and (b) Solution pH

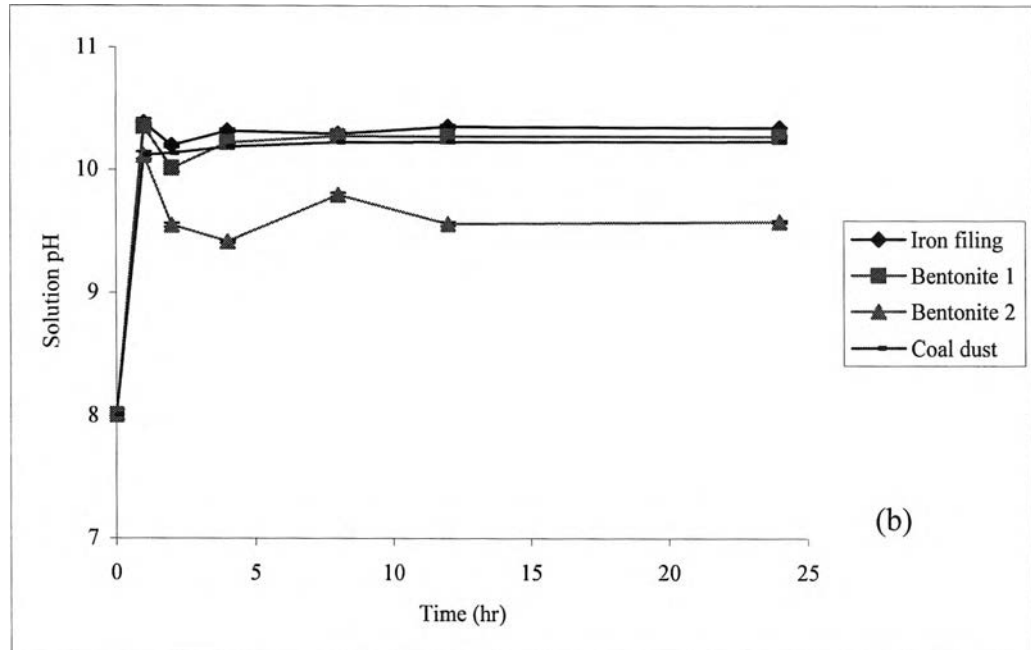
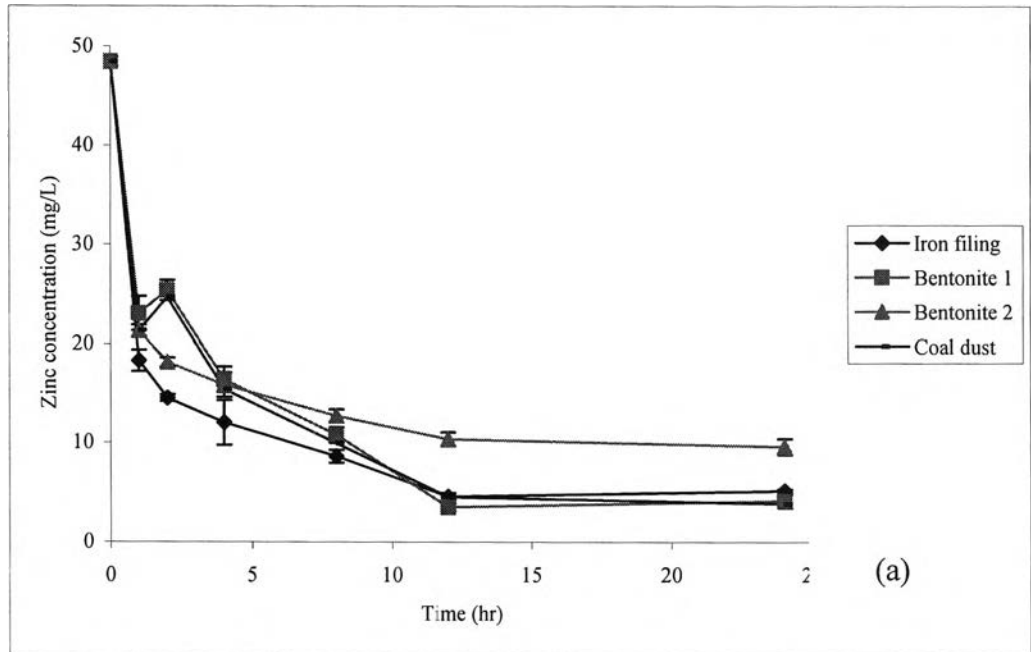


Figure 4.7 Results of batch kinetic tests for iron filing, bentonite 1, bentonite 2 and coal dust at initial pH 8.01: (a) Zinc concentration and (b) Solution pH

4.4.1.1 Effect of initial zinc concentration on zinc removal

Effect of initial zinc concentration on zinc removal was determined by using iron filing, bentonites and coal dust as media of sorption. The initial solution pH solution and mass of sorbent were maintained at 3.72 and 2 g, respectively. Three initial zinc concentrations (48.13, 60.53 and 92.65 mg/l) were used. The tumbling time was set at 24 hours which was found to be sufficient to ensure equilibrium.

Zinc removal during batch kinetic tests for waste foundry sands as a function of initial zinc concentration are shown in Figure 4.8. At initial zinc concentration 48.13 mg/l showed the best removal efficiency of zinc among these initial zinc concentrations. The removal data are summarized in Table 4.8.

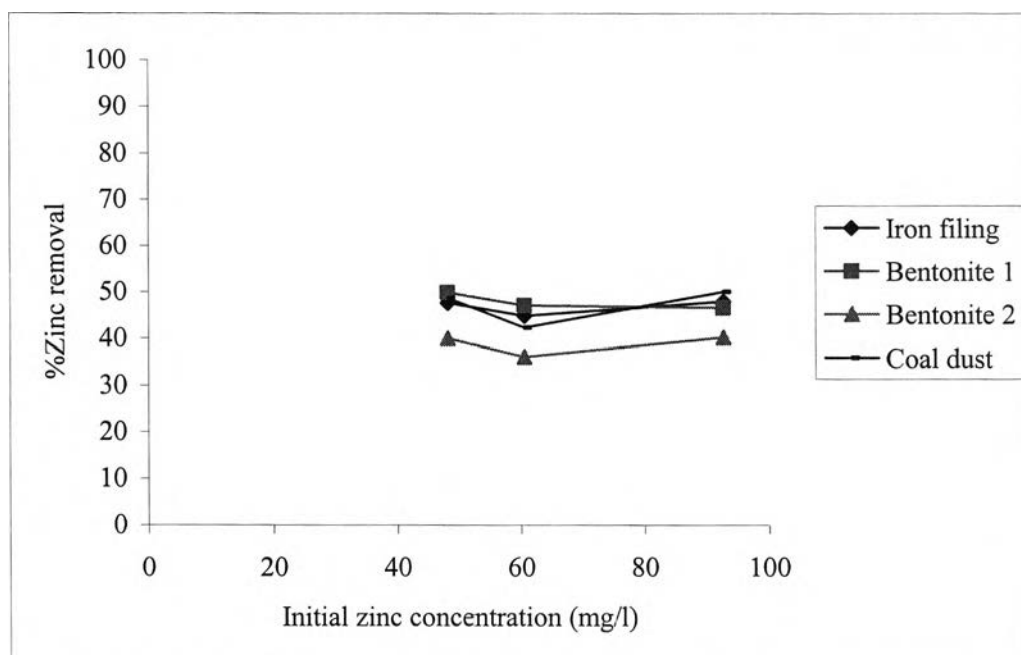


Figure 4.8 Zinc removals during batch kinetic tests for iron filing, bentonites and coal dust as a function of initial zinc concentration

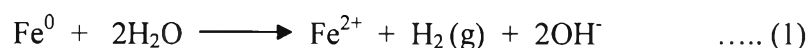
Table 4.8 Zinc removals by bentonites, iron filing, and coal dust for different initial concentration

Media	Clay (%)	Total Iron Content (%)	TOC (%)	Equilibrium concentration for various initial concentration					
				C ₁ = 48.13 mg/l	% removal	C ₂ = 60.53 mg/l	% removal	C ₃ = 92.65 mg/l	% removal
Iron filing	Not Applicable	79.55	Not Applicable	25.20	47.64	33.41	44.81	48.30	47.87
Bentonite 1	82.00	Not Applicable	0.24	24.15	49.83	32.05	47.05	49.53	46.54
Bentonite 2	76.30	Not Applicable	0.14	28.88	40.00	38.72	36.03	55.39	40.22
Coal dust	Not Applicable	Not Applicable	Not Applicable	24.72	48.64	34.91	42.33	46.34	49.99

4.4.1.2 Effect of equilibrium solution pH on zinc removal

Zinc removal for iron filing, bentonites and coal dust as a function of initial solution pH is shown in Figure 4.9. The initial concentration and amount of sorbent were maintained at 50 mg/l and 2 g, respectively. Three different initial solution pHs (3.72, 6.59 and 8.01) were used. The results showed that amount of zinc removed increased as solution pH increased. The removal data are summarized in Table 4.9 – 4.10.

For the iron filing, the zinc concentrations continuously decreased may be from ion exchange as the following reaction (Stumm et al. 1981):



Where Fe^0 is zero valence iron, Fe^{2+} is ferrous iron, $\text{H}_2(\text{g})$ is hydrogen gas, and OH^- is hydroxide iron.

The increment of the zinc adsorption on these bentonites appears to involve two distinct mechanisms which are ion-exchange reaction at permanent-charge sites and formation of complexes with the surface hydroxyl groups (Bradbury and Baeyens 1997 and Ikhsan et al. 2004).

The formation of complexes with surface hydrous oxide can occur by amphoteric groups ($\equiv\text{SOH}$), which can be silanol groups or aluminol groups and are able to form inner sphere complexes such as $\equiv\text{S}-\text{O}-\text{M}^{(n-1)+}$ (Kraepiel et al. 1999 and Barbier et al. 2000). The adsorption mechanisms of Zn^{2+} related to surface complexation are as follows:



Sorption of zinc on surface hydrous oxide is influenced by pH-dependent. As the solution pH increased, more zinc was sorbed on the metal oxides due to the negativity charge of the metal oxides (Sparks 1995).

However, sorption of zinc onto these bentonites at higher pH may also involve precipitation of zinc hydroxide, but it is difficult to distinguish between adsorption and precipitation processes (Dzombak et al. 1985)

The zinc adsorptions onto coal dust depend on amount of organic matter. Similar to bentonites, the zinc concentrations continuously decreased may be from two possible mechanisms: binding of metal ions to solid organic matter or binding to dissolved organic matter (Kordel et al. 1997 and Gustafsson et al. 2002).

Table 4.9 Zinc removals by bentonites, iron filing, and coal dust for different initial pH

Media	Clay (%)	Total Iron Content (%)	TOC (%)	C ₀ (mg/l)	Equilibrium concentration for various initial pH					
					pH = 3.72	% removal	pH = 6.59	% removal	pH = 8.01	% removal
Iron Filing	Not Applicable	79.55	Not Applicable	48.13	25.20	47.64	8.83	81.65	4.56	90.52
Bentonite 1	82.00	Not Applicable	0.24	48.13	24.15	49.83	8.68	81.97	3.50	92.72
Bentonite 2	76.30	Not Applicable	0.14	48.13	28.88	40.00	12.43	74.17	10.34	78.52
Coal dust	Not Applicable	Not Applicable	Not Applicable	48.13	24.72	48.64	10.74	77.69	4.53	90.59

Table 4.10 Equilibrium solution pHs of bentonites, iron filing, and coal dust for different initial pH

Media	Clay (%)	Total Iron Content (%)	TOC (%)	Equilibrium solution pH					
				Initial pH (1)	Eq. pH (1)	Initial pH (2)	Eq. pH (2)	Initial pH (3)	Eq. pH (3)
Iron Filing	Not Applicable	79.55	Not Applicable	3.72	7.80	6.59	8.49	8.01	10.34
Bentonite 1	82.00	Not Applicable	0.24	3.72	8.06	6.59	8.56	8.01	10.27
Bentonite 2	76.30	Not Applicable	0.14	3.72	7.26	6.59	8.72	8.01	9.58
Coal dust	Not Applicable	Not Applicable	Not Applicable	3.72	7.53	6.59	8.49	8.01	10.23

Table 4.11 Zinc removals during batch kinetic tests for iron filing, bentonites and coal dust as a function of initial solution and equilibrium pH

Initial pH	Media	C ₀ (mg/l)	C (mg/l)	% removal of zinc	Equilibrium pH
3.72	Iron filing	48.13	25.20	47.64	7.90
	Bentonite 1	48.13	24.15	49.83	8.06
	Bentonite 2	48.13	28.88	40.00	7.26
	Coal dust	48.13	24.72	48.64	7.53
6.59	Iron filing	48.13	8.83	81.65	8.49
	Bentonite 1	48.13	8.68	81.97	8.56
	Bentonite 2	48.13	12.43	74.17	8.72
	Coal dust	48.13	10.74	77.69	8.49
8.01	Iron filing	48.13	4.56	90.52	10.34
	Bentonite 1	48.13	3.50	92.72	10.27
	Bentonite 2	48.13	10.34	78.52	9.58
	Coal dust	48.13	4.53	90.59	10.23

4.5 Results of batch sorption tests using waste foundry sands

4.5.1 Results of batch kinetic tests

Batch kinetic tests were conducted to ensure that the time duration for experiments were sufficient to reach an equilibrium state and also to determine the sorption kinetics such as effect of initial solution pH and zinc concentration. Foundry sands were used as media of zinc sorption.

The experimental conditions are shown in Table 4.11. Groundwater contaminated with zinc was synthesized for experiments in laboratory scale by dissolving zinc chloride in DI water to yield an expected zinc concentration of 50 mg/l and mixed with sodium azide (0.1% by weight) to prevent biological activity. Three different solutions pH were selected as initial pH 3.72, 6.59 and 8.01 according to typical range of groundwater characteristic. No pH buffer was used. The initial solution pH was adjusted with either 1.0 M of reagent grade nitric or sodium hydroxide.

Table 4.12 Experiment conditions for batch sorption tests using foundry sands

Media	Mass of media (g)	Bentonite (%)	Iron Content (%)	TOC (%)
Sand 1	2	19.14	4.37	2.03
Sand 2	2	10.84	0.48	1.82
Sand 3	2	1.44	4.46	1.17
Sand 4	2	-	-	0.47

As same as the results from batch kinetic using iron filing, bentonites and coal dust as sorbents, the zinc concentration decreased as time passed for all foundry sands

regardless of pH of the solutions. The equilibrium concentrations were found within 24 hours. Typical results for in concentration reduction are shown in Figure 4.12 – 4.14 (a). Relatively highest zinc concentrations that remain in solution were observed for sand 4 than others.

Figure 4.12 – 4.14 (b) show the results of solution pH as a function of contact time. The results show that the solution pH continued to increase as time progressed for all foundry sands. The solution pH also stabilized within 24 hours which may suggest the equilibrium.

The increases in equilibrium solution pHs were proportional to the initial pH. The presence of clay, TOC and total iron resulted in elevated solution pH, which caused the formation of zinc hydroxide and provided more sorption sites for zinc. In addition, concentration of zinc decreases as pH increases due to precipitation of complexation of zinc on metal oxide surface and precipitation of $Zn(OH)_2$ at high pH that affect the removal of zinc.

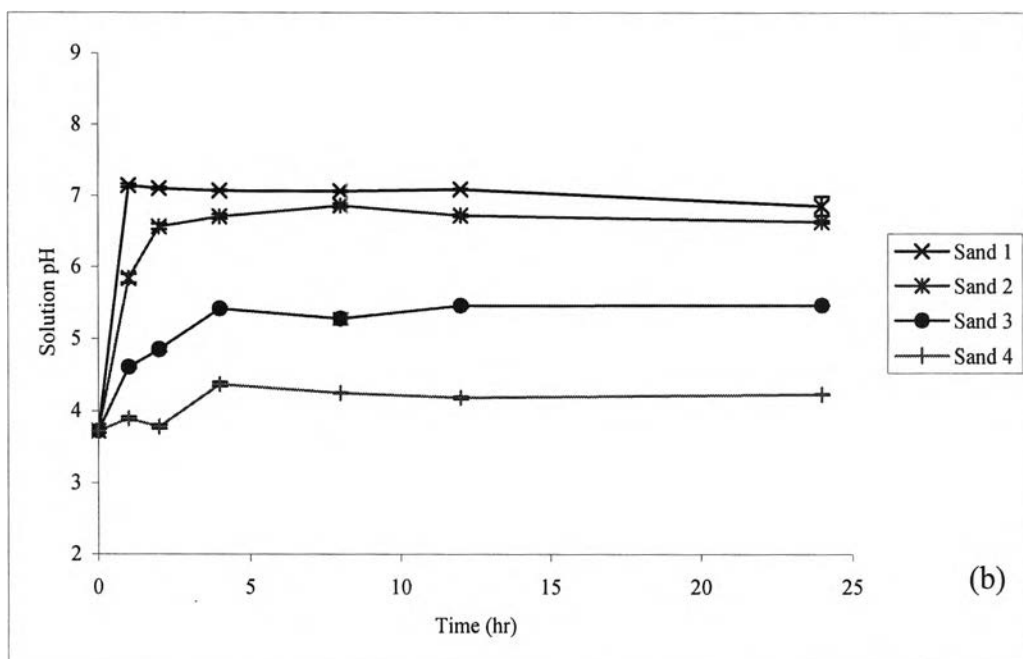
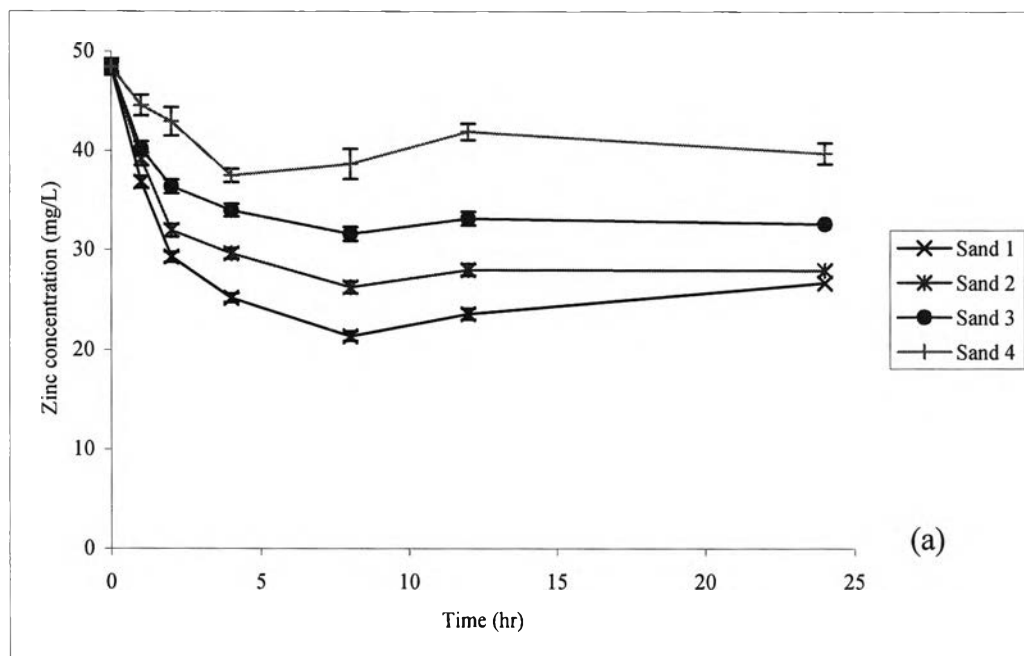


Figure 4.9 Results of batch kinetic tests using waste foundry sands at initial pH 3.72: (a) Zinc concentration and (b) Solution pH

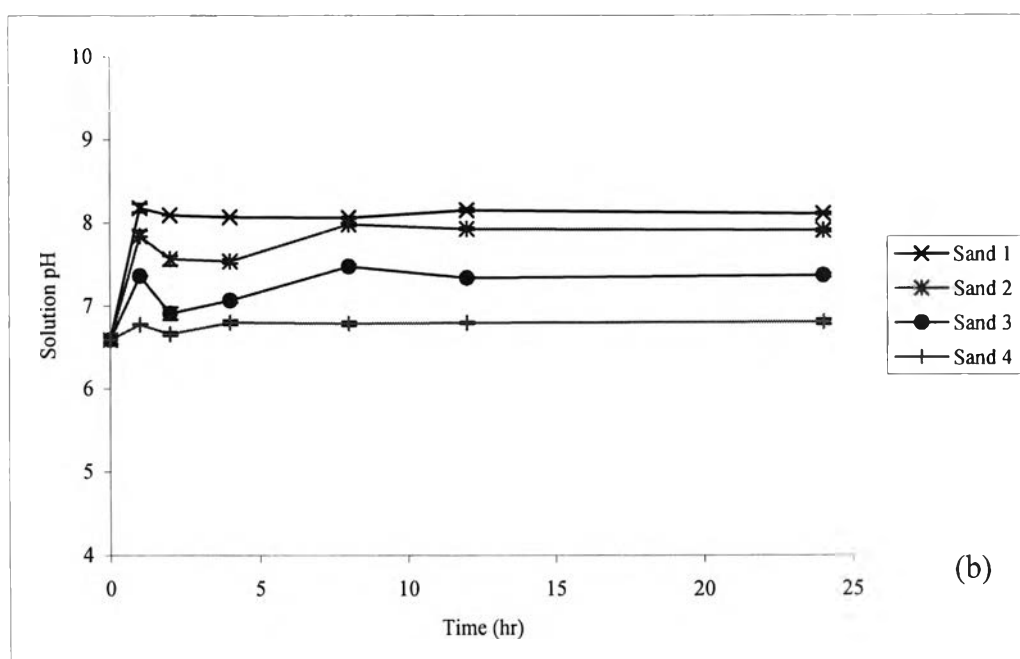
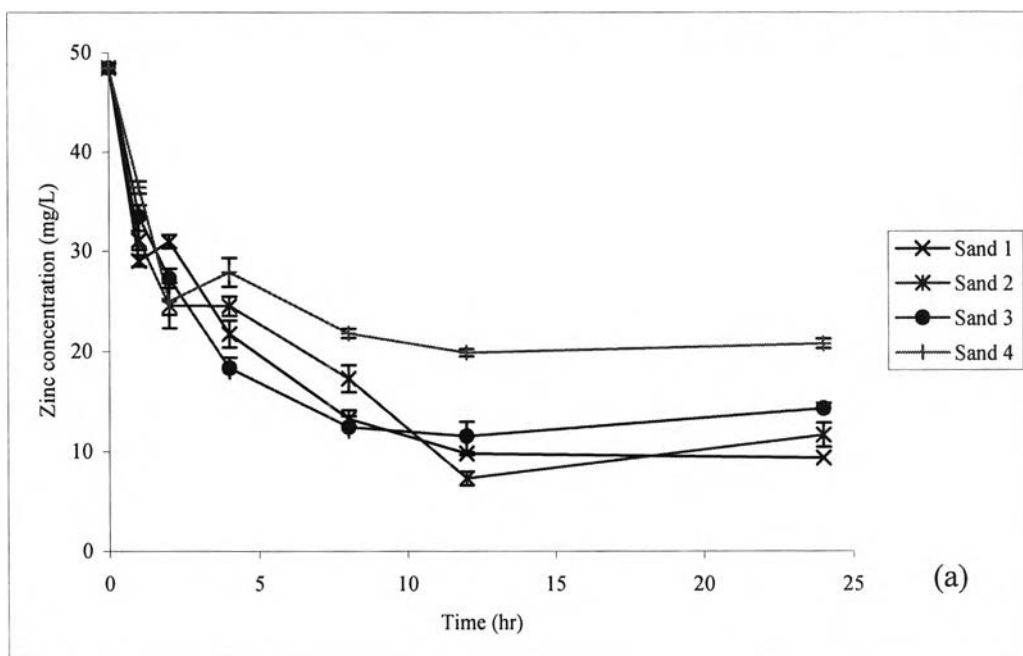


Figure 4.10 Results of batch kinetic tests using waste foundry sands at initial pH 6.59: (a) Zinc concentration and (b) Solution pH

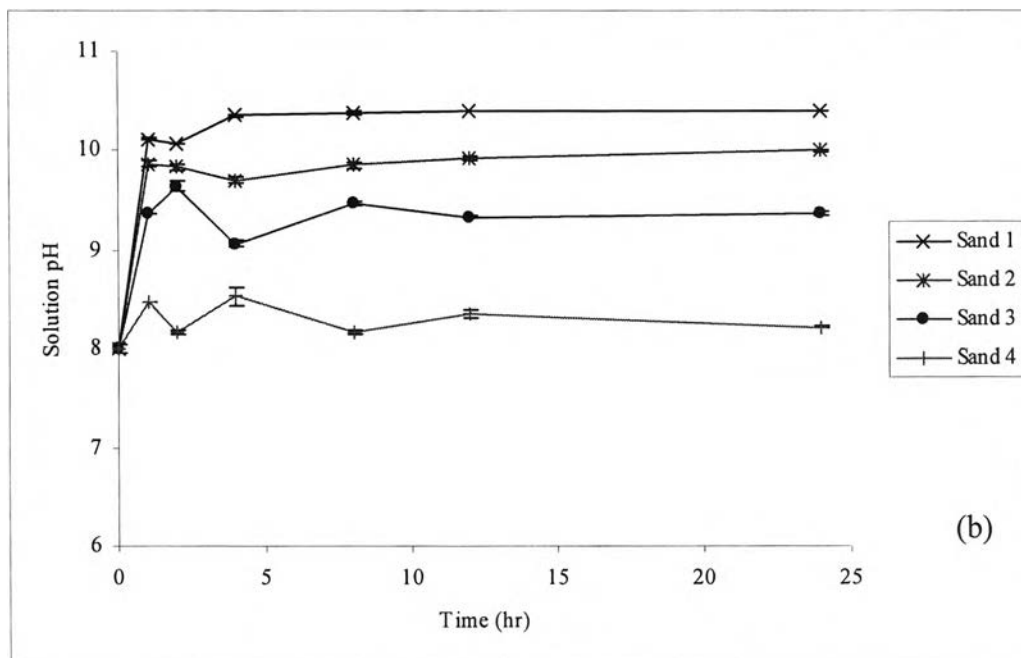
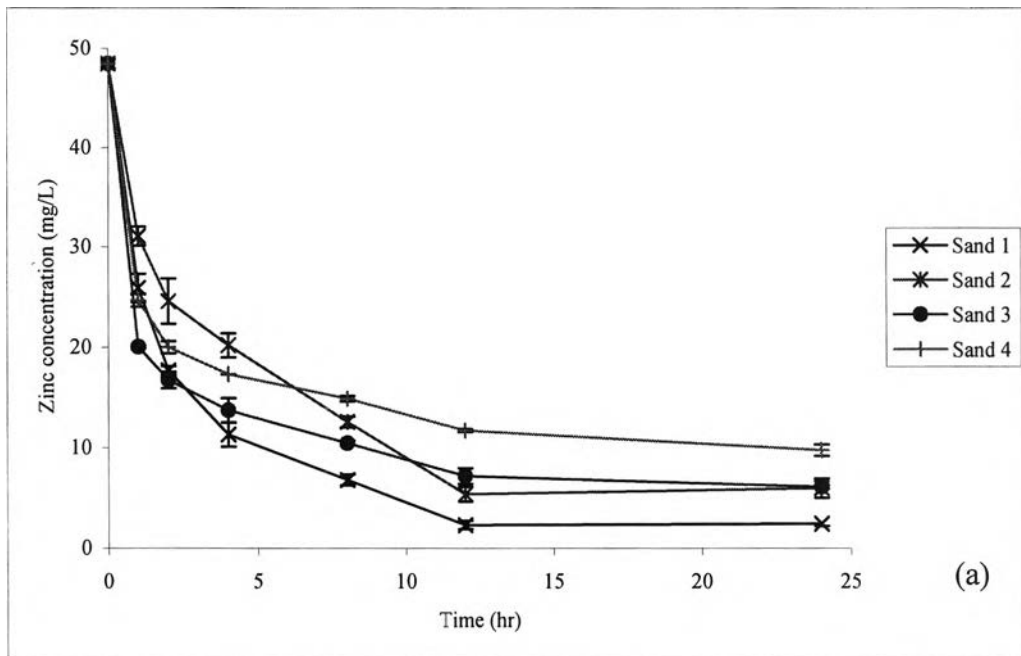


Figure 4.11 Results of batch kinetic tests at initial pH 8.01: (a) Zinc concentration and (b) Solution pH

4.5.1.1 Effect of initial zinc concentration on zinc removal

Effect of initial zinc concentration on zinc removal was determined by using Sand 1, Sand 2, Sand 3 and Sand 4 as media of sorption. The initial solution pH and mass of foundry sands were maintained at 3.72 and 2 g, respectively. Three initial zinc concentrations (50, 60.53 and 92.65 mg/l) were used. The tumbling time was set at 24 hours which was found to be sufficient to ensure equilibrium.

Figure 4.15 shows zinc removal during batch kinetic tests for waste foundry sands as a function of initial zinc concentration. As same as iron filing, bentonites and coal dust, initial zinc concentration 50 mg/l showed the best removal efficiency of zinc among these initial zinc concentrations. The removal data are summarized in Table 4.12.

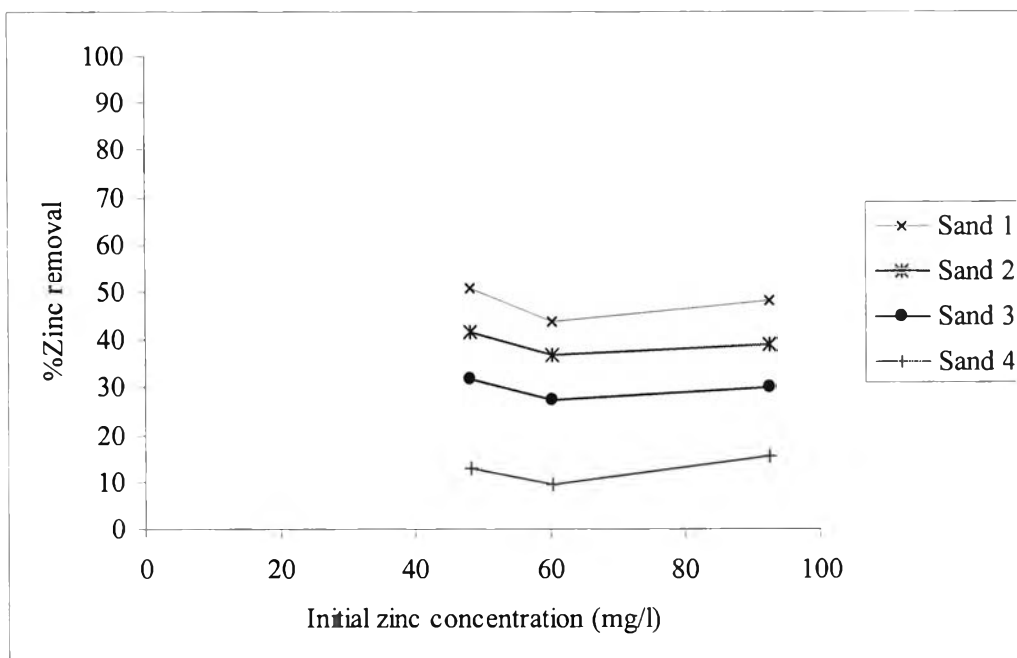


Figure 4.12 Zinc removals during batch kinetic tests for waste foundry sands as a function of initial zinc concentration

Table 4.13 Zinc removal by waste foundry sands for different initial concentration

Media	Clay (%)	Total Iron Content (%)	TOC (%)	Equilibrium concentration for various initial concentration					
				C ₁ = 48.13 mg/l	% removal	C ₂ = 60.53 mg/l	% removal	C ₃ = 92.65 mg/l	% removal
Sand 1	19.14	4.37	2.03	23.57	51.02	33.86	44.06	47.97	48.23
Sand 2	10.84	0.48	1.82	28.00	41.82	38.06	37.13	56.22	39.32
Sand 3	1.44	4.46	1.17	32.68	32.10	43.84	27.58	64.79	30.07
Sand 4	0.00	0.00	0.47	41.90	12.95	54.75	9.55	78.34	15.45

4.5.1.2 Effect of equilibrium solution pH on zinc removal

Zinc removal for foundry sands waste as a function of equilibrium solution pH is shown in Table 4.16. As expected, the amount of zinc removed increased as solution pH increased. The mechanism of the specific adsorption at high pH due to the surface complexation reaction is influenced by electrostatic attraction between the surface charges and dissolved ion (Farrah and pickering 1976 and Abollino et al. 2003). In addition, removal efficiency of zinc increased as much as equilibrium solution pH increased for all foundry sands and all initial solution pH.

However, blanks without waste sand or any media were used as control to estimate loss of zinc. Blank test were conducted at different initial solution pHs to estimate zinc removal by precipitation. The initial solution pH was adjusted with 1.0 M of HNO_3 or NaOH .

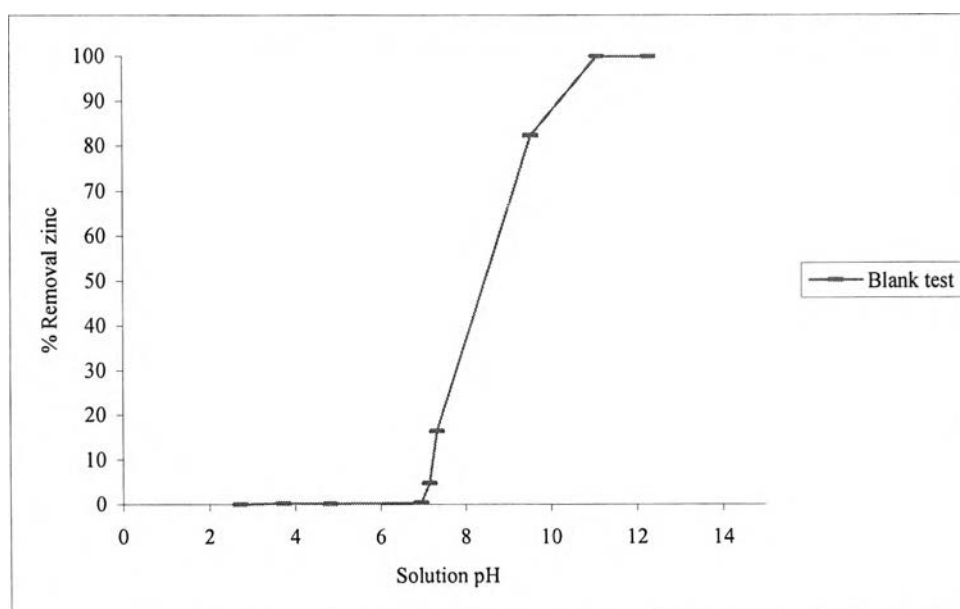
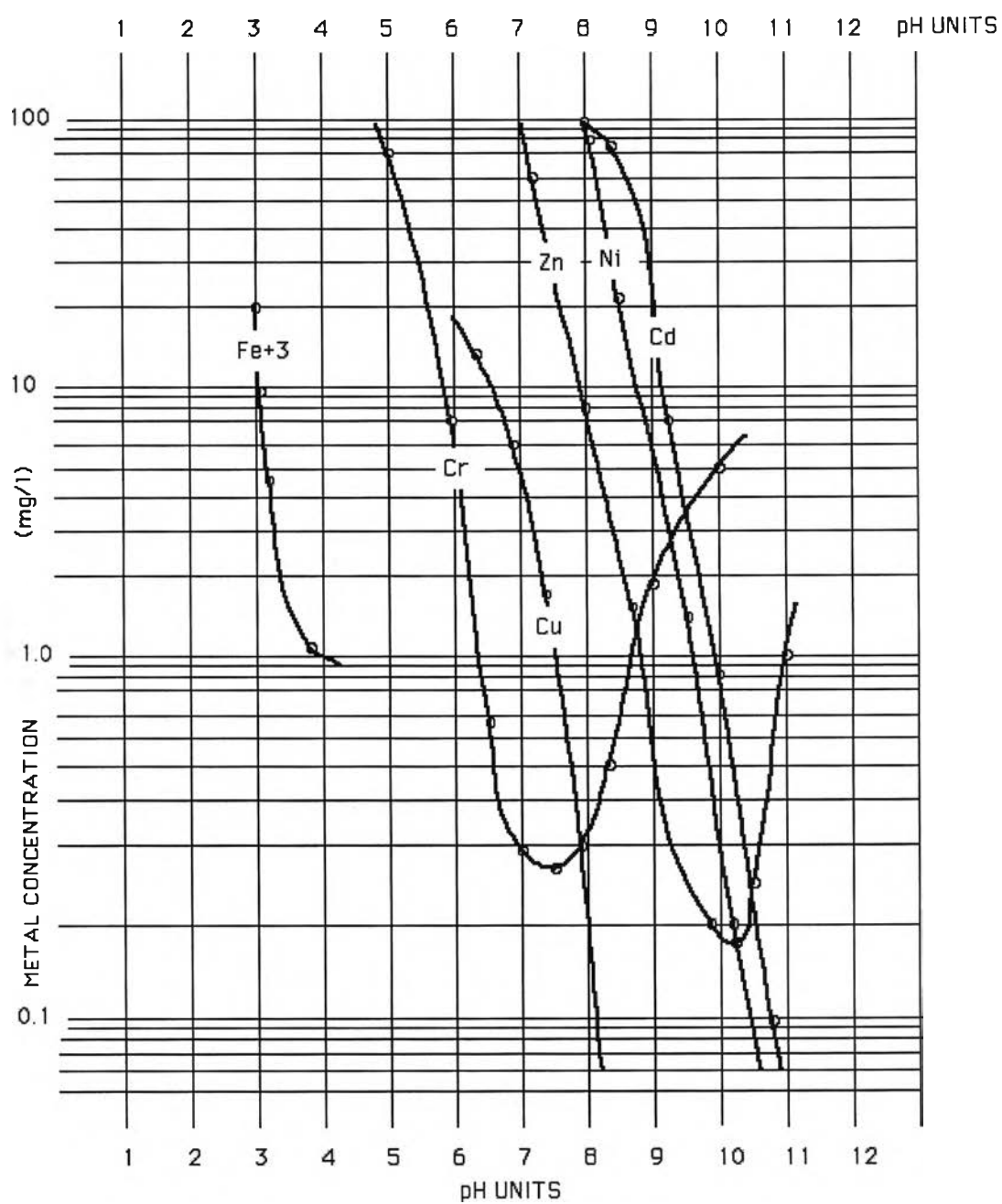


Figure 4.13 Zinc removals during batch kinetic tests at different solution pH

The results showed that precipitation of zinc begins at pH 7 as shown in Figure 4. According to the solubility constant of Zn(OH)_2 ($K_{sp} = 1.2 \times 10^{-17}$, at 18 - 25°C), precipitation of zinc hydroxide as a function of solution pH is shown in Figure 4.19. The precipitation of zinc hydroxide was observed at pH 7.3 (David et al. 1994). Therefore, the result obtained from this experiment is similar to the theoretical that describe previously. At pH less than 7, zinc removed by waste foundry sand is primarily by sorption process whereas at pH greater than 7, zinc was removed by a combination of sorption and precipitation. The removal data are summarized in Table 4.13– 4.14.



Source: EPA Technology Transfer

Figure 4.14 Metal concentration as a function of solution pH

(EPA Technology Transfer)

Table 4.14 Zinc removal by waste foundry sands for different initial pH

Media	Clay (%)	Total Iron Content (%)	TOC (%)	C ₀ (mg/l)	Equilibrium concentration for various initial pH					
					pH = 3.72	% removal	pH = 6.59	% removal	pH = 8.01	% removal
Sand 1	19.14	4.37	2.03	48.13	23.57	51.02	9.78	84.77	3.66	92.39
Sand 2	10.84	0.48	1.82	48.13	28.00	41.82	7.33	79.68	4.38	90.89
Sand 3	1.44	4.46	1.17	48.13	32.68	32.10	11.53	76.04	6.30	86.92
Sand 4	0.00	0.00	0.47	48.13	41.90	12.95	19.86	58.74	15.04	68.75

Table 4.15 Equilibrium solution pHs of waste foundry sands for different initial pH

Media	Clay (%)	Total Iron Content (%)	TOC (%)	Equilibrium solution pH					
				Initial pH (1)	Eq. pH (1)	Initial pH (2)	Eq. pH (2)	Initial pH (3)	Eq. pH (3)
Sand 1	19.14	4.37	2.03	3.72	6.86	6.59	8.11	8.01	10.40
Sand 2	10.84	0.48	1.82	3.72	6.64	6.59	7.91	8.01	10.00
Sand 3	1.44	4.46	1.17	3.72	5.47	6.59	7.37	8.01	9.37
Sand 4	0.00	0.00	0.47	3.72	4.23	6.59	6.81	8.01	8.22

Table 4.16 Zinc removals during batch kinetic tests for waste foundry sands as a function of initial solution and equilibrium pH

Initial pH	Media	C ₀ (mg/l)	C (mg/l)	% removal of zinc	Equilibrium pH
3.72	Sand 1	48.13	23.57	51.02	6.86
	Sand 2	48.13	28.00	41.82	6.64
	Sand 3	48.13	32.68	32.10	5.47
	Sand 4	48.13	41.90	12.95	4.23
6.59	Sand 1	48.13	9.78	79.68	8.11
	Sand 2	48.13	7.33	84.77	7.91
	Sand 3	48.13	11.53	76.04	7.37
	Sand 4	48.13	19.86	58.74	6.81
8.01	Sand 1	48.13	3.66	92.39	10.40
	Sand 2	48.13	4.38	90.89	10.00
	Sand 3	48.13	6.30	86.92	9.37
	Sand 4	48.13	15.04	68.75	8.22

4.5.2 Effect of clay, iron and TOC content on zinc removal

A multivariate regression analysis was conducted to determine the effect of clay content, total iron content and TOC on zinc removal for each initial solution pH. A significance level of 0.05 was used. The regression equations for standardized coefficients are as follows:

At initial solution pH 3.72

$$\text{Removal (\%)} = 3.414 + 0.089 \text{ Clay} + 1.081 \text{ Iron} + 20.289 \text{ TOC}$$

At initial solution pH 6.59

$$\text{Removal (\%)} = 50.189 - 0.385 \text{ Clay} + 1.148 \text{ Iron} + 18.194 \text{ TOC}$$

At initial solution pH 8.01

$$\text{Removal (\%)} = 58.275 - 0.770 \text{ Clay} + 0.825 \text{ Iron} + 22.287 \text{ TOC}$$

Where: Clay is the clay content (%), Iron is the iron content (%) and TOC is the total of organic carbon content (%)

From the experiments, the parameters that have a significant effect on the zinc removal are studied. The results show that clay, iron and total organic content have a significant effect on the zinc removal. The partial regression coefficient of clay content which less than that of iron content can be indicated that clay has less significant effect on the zinc removal than iron content whereas total organic carbon which has the highest partial regression coefficient show the most significant among these parameters. In addition, amount of zinc removal increase as the amount of clay, iron and total organic carbon content increase.

However, regression planes intersect the y – axis at 3.414, 50.189 and 58.275 for initial solution pH 3.72, 6.59 and 8.01, respectively. These might be caused that there are other factors in foundry sand that contributing the removal of zinc especially when solution pH increased. The possible reactions that promote zinc removal are precipitation due to complexation of zinc on metal oxide surface and precipitation of $Zn(OH)_2$ when solution pH is higher than 7.

4.6 Comparison test between foundry sand waste and synthetic foundry sand

In this part, the tests were conducted to compare the removal efficiency of zinc onto waste foundry sand and synthetic sand. Synthetic foundry sand were synthesized using an appropriate mix of pure sand, bentonite, and other components according to the proportion of Sand 1 which has the greatest sorptive capacity among those sands. The iron filing was used to provide iron content in sand whereas bentonite provided clay content and coal dust provided organic carbon. The proportional of synthetic sand is shown in Table 4.15. The sand consisted of 4.37 % of iron, 19.14 % of clay and 2.03 % of TOC.

As a result, the removal efficiency of zinc by synthetic sand was slightly higher than that of Sand 1.

Table 4.15 Zinc removed by Sand 1 compared with synthetic sand using initial zinc concentration 50 mg/l at pH 3.72

Media	Iron (%)	Clay (%)	TOC (%)	Zinc removal (%)	Mass sorbed (mg/kg)
Sand 1	4.37	19.14	2.03	51.02	613.89
Synthetic sand	4.37	19.14	2.03	59.38	714.48
Regression	4.37	19.14	2.03	51.03	614.25

The multivariate regression equations for zinc removal at initial solution pH 3.21 were used for enhancing the removal efficiency of zinc by synthetic waste foundry sands as input. The experiments were used to ensure the effect of significant index parameters for the zinc removal. Enhanced synthetic sand consisted of 45 % of iron, 19.14% of clay and 2.03 % of TOC.

Zinc removed by enhanced synthetic sand compared with data obtained from multivariate regression equation is summarized in Table 4.16. The result shows that zinc removed by enhanced synthetic sand was comparable with data obtained from regression equation. The zinc removal by enhanced synthetic equal to 89.70% and amount of zinc sorbed into the sand is 1079.31 mg/kg whereas those of regression equation were 94.95% and 1,142.50 mg/kg, respectively.

Table 4.16 Zinc removed by enhanced synthetic sand compared with data obtained from multivariate regression equation

Media	Iron (%)	Clay (%)	TOC (%)	Zinc removal (%)		Mass sorbed (mg/kg)	
				Regression	Experiment	Regression	Experiment
Enhanced synthetic sand	45	19.14	2.03	94.95	89.70	1,142.50	1,079.31