

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Leaching test

4.1.1 Total metal concentrations

The samples selected for the leaching tests included new untreated and CCA-treated softwoods and hardwoods, weathered CCA-treated hardwoods, and ash from the burning of untreated and CCA-treated hardwoods. The wood samples were collected from two wood factories located in Chiang Mai, Thailand. The retention value of all CCA-treated wood samples reported by the factory was 0.5 pcf or 8.01 kg/m³.

All samples used in the leaching tests were digested and analyzed for their total metal contents. The analysis of each sample was replicated. The results of the analyses are presented in Appendix A, and the average values are presented in Table 4.1. The results showed that all metal contents contained in the CCA-treated wood and ash burned from CCA-treated wood were very high, compared with the untreated wood and ash burned from untreated wood. When the metal contents in the outer 6/10" layer of hardwoods and softwoods were taken into consideration, it was found that the arsenic and chromium contents were in the same order, while the copper content of the hardwood was less than that of the softwood. The metal contents in the outer 6/10" layer of the new CCA-treated hardwood sample were found to be 2.8-3.1 times higher than the levels found in the cross-section samples. The ratios were higher in the CCA-treated softwood (9-16 times). The results clearly showed that the CCA-solution penetrates through the inner part of the hardwood better than the softwood, and most of the metal contents from the CCA solution are fixed in the outer layer of the wood.

The metal contents of the weathered CCA-treated wood cross-section sample were found to be 1.7-2.0 and 9.5-12 times higher than those of new CCA-

treated hardwood and softwood, respectively. The retention values used to treat the weathered CCA-treated wood was not clearly identified by the wood factory. However, according to the results obtained, the retention values may have been higher than that of the new treated wood.

Table 4.1 Metal content of the samples used in the leaching tests (average concentration of three samples)

Samples description		As (mg/kg)	Cr (mg/kg)	Cu (mg/kg)
New untreated hardwood	outer 6/10"	0.20	0.50	10.30
	cross section	0.00	0.00	1.47
New CCA-treated hardwood	outer 6/10"	1483	2513	1401
	cross section	514.6	813.1	452.0
New untreated softwood	outer 6/10"	0.53	1.30	3.17
	cross section	0.00	0.00	4.23
New CCA-treated softwood	outer 6/10"	1296	2475	681.1
	cross section	89.92	150.6	71.80
Weathered CCA- treated hardwood	cross section	855.5	1507	906.4
Ash untreated wood	cross section	3.73	1.27	4.93
Ash CCA-treated wood	cross section	23370	62720	31300

All metal concentrations in the ash from burned CCA-treated hardwood were very high, compared to the metal concentration in the untreated hardwood.

4.1.2 TCLP and WET results

The TCLP was designed to provide a relatively quick test that could be performed on a solid waste to determine whether that waste should be characterized as hazardous and thus be managed in a more controlled operation. The acetic acid use in this test simulates the organic acids produced from decomposing waste in anaerobic environments such as a landfill. The regulations require the concentration of specific compounds in the TCLP leachate to be compared to the TC concentrations in the regulation (US EPA, 1992). The waste extraction test (WET) is a California-specific leaching procedure used to determine whether a solid waste is hazardous. This test is also used as a standard test by the Department of Industrial Work (DIW) of Thailand to classify the disposed waste in municipal solid waste landfills. The results of the WET were compared to the soluble threshold limit concentration (STLC) values listed in the Notification of the Ministry of Industrial B.E. 2548 (MOI, 2005). The WET leaching fluid is a buffered citric acid solution.

The results of the TCLP and WET batch leaching tests for the eleven wood samples are summarized in Table 4.2 and Figures 4.1, 4.2, and 4.3. The TCLP and WET tests showed that the arsenic, chromium, and copper concentrations leached from almost all untreated wood and ash from burned untreated wood were below the detection limits (BDLs).

According to the TCLP test, in general, arsenic leached at higher concentrations than chromium (from all CCA-treated wood samples except for the ash sample from CCA-treated wood) and copper (from all the CCA-treated wood samples except for the weathered CCA-treated wood sample). However, chromium leached out from the ash from the CCA-treated wood sample at the highest concentration, compared with the other two metals. The CCA-treated hardwood leached higher metal concentrations than the softwood. The higher metal concentrations were also observed in the outer 6/10" layer of the samples, compared with the cross-section of the samples.

Table 4.2 Summary of the TCLP and WET results (average concentration of three samples)

Samples	Sample ID	TCLP (mg/L)			WET (mg/L)		
		As	Cr	Cu	As	Cr	Cu
Untreated hardwood outer 6/10"	a	BDL*	BDL**	BDL***	BDL*	BDL**	0.06
Untreated hardwood Cross-section	b	BDL	BDL	BDL	BDL	BDL	BDL***
Untreated softwood outer 6/10"	c	BDL	BDL	BDL	BDL	BDL	BDL
Untreated softwood Cross-section	d	BDL	BDL	BDL	BDL	BDL	BDL
Ash burned from untreated wood	e	BDL	BDL	BDL	BDL	BDL	BDL
CCA-treated hardwood outer 6/10"	f	17.70	2.64	5.56	17.17	5.89	23.89
CCA-treated hardwood Cross-section	g	9.21	1.14	4.83	9.19	4.50	10.55
CCA-treated softwood outer 6/10"	h	3.30	0.51	1.15	11.34	3.57	13.64
CCA-treated softwood cross section	i	1.74	0.26	0.82	1.36	0.85	0.62
Weathered CCA-treated hardwood cross section	j	4.92	0.46	6.70	1.67	0.46	0.96
Ash from CCA-treated wood	k	116.9	3862	84.03	108.5	1522	114.4

Remarks: BDL* : Below the detection limit of As: 0.005 mg/L

BDL** : Below the detection limit of Cr: 0.06 mg/L

BDL*** : Below the detection limit of Cu: 0.05 mg/L

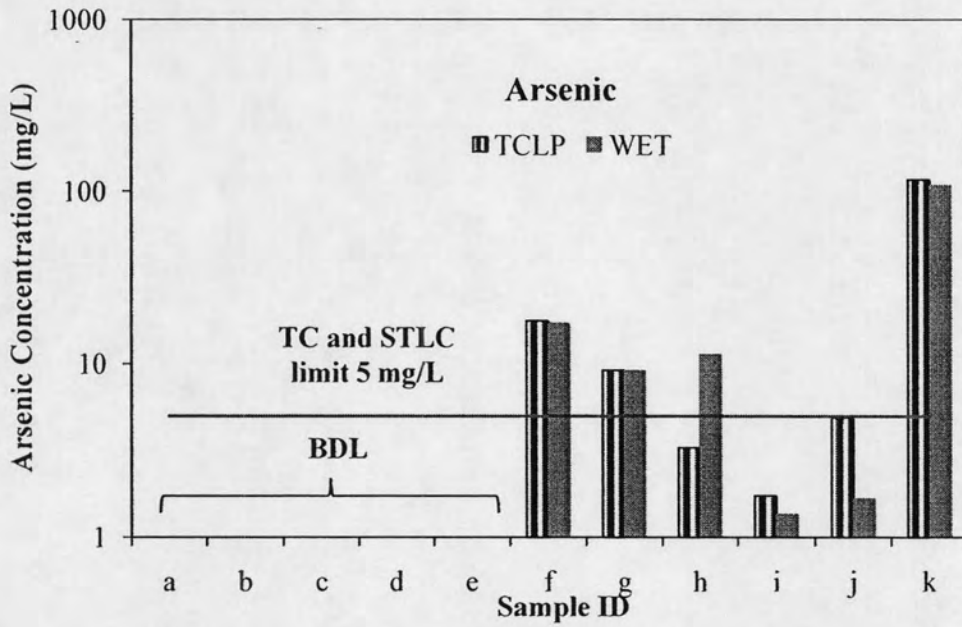


Figure 4.1 TCLP and WET arsenic results of the eleven woods and ash samples

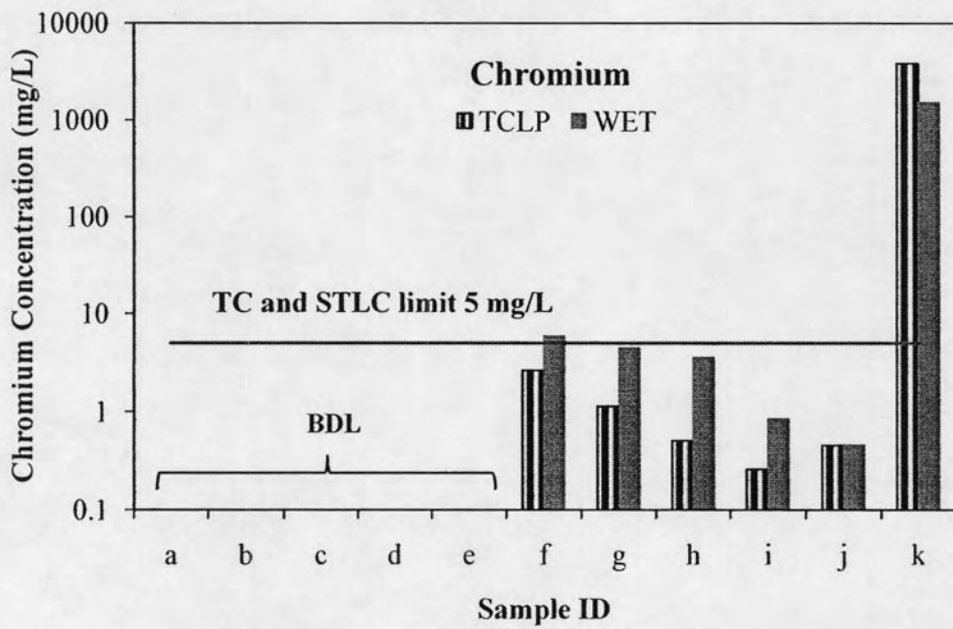


Figure 4.2 TCLP and WET chromium results of the eleven woods and ash samples

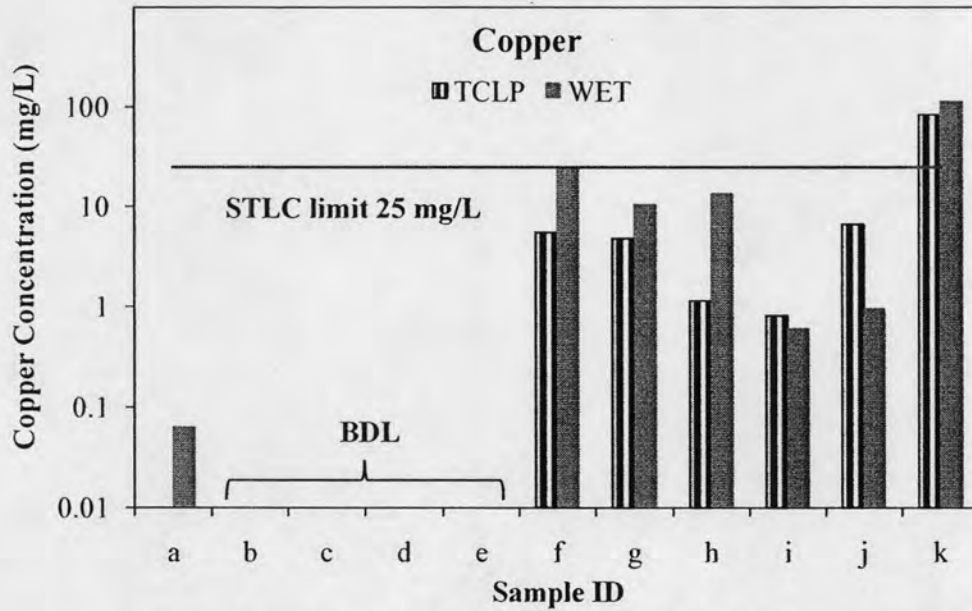


Figure 4.3 TCLP and WET copper results of the eleven wood and ash samples

In the WET test, copper leached out at a higher level than arsenic in 3 of the 5 wood samples while the opposite trend was observed in the rest of the wood samples. The concentrations of chromium and copper in most samples that were put through the WET test were higher than the concentrations produced by the TCLP test. These results were similar to the results of Townsend et al. (2004) and Hooper et al. (1998). The higher chelating ability of citrate was the cause of this observation. In the TCLP test, the leached chromium concentration from the CCA-treated wood samples was lowest in comparison to those of the other two metals; however, the leached chromium concentration from the ash sample produced by CCA-treated wood was highest, when compared with the concentrations of the other two metals.

Table 4.3 shows the fractions (%) of the metals that leached from the CCA-treated wood from the total metal concentrations in the samples by both leaching tests. In the TCLP test, arsenic leached from almost all samples (except for the weathered CCA-treated wood) at the highest percentages; it was followed by copper and chromium, respectively. However, the highest fraction of copper leached

out from CCA-treated wood during the WET test (3 of 5 CCA-treated wood samples), followed by arsenic and chromium. It was found that the fraction of chromium leached out from ash burned from CCA-treated wood was very high, compared with the fractions of the other two metals. When the wood type was considered, all three metals leached out from the outer 6/10" layer of the hardwood in higher fractions than those produced by the softwood. This trend supports results previously reported by Lelow (2004). The leached metal concentrations from the weathered wood were less than the concentrations from the new wood samples. It might be because the metals had been leaching out from the weathered wood along its lifetime. It has been reported that CCA in preserved wood can leach from the wood into surrounding soil after exposure to rain and water (CDHS, 1987). The result of ash burned from CCA-treated wood showed the fraction of chromium release was 30.8% in the TCLP test and 97.0% in the WET. The fractions of leached arsenic and copper were found to be 2.50 and 1.34 from the TCLP and 18.5 and 14.6 from the WET, respectively. The results of chromium leaching from ash in the both tests were higher than the results from the CCA-treated wood. The pH of ash enhances the leaching of high fractions of chromium and this trend was also found in the study of Solo-Gabriele et al. (2004).

Generally, the fractions of WET were greater than TCLP because of a different extraction fluid, a longer mixing period, and a lower solid to liquid ratio. The WET extraction fluid contains citric acid, which is a strong chelating agent. Because of this, the WET test usually extracts higher quantities of most metal than the TCLP test (Hooper, 1998).

4.1.3 Evaluating the potential impacts on landfills

At present, some CCA-treated woods are disposed of along with construction and demolition debris or MSW, or piled up on land for future reuse. In addition, some woods are burned and the ash generated is usually dumped directly on land. The above mentioned practices have the potential to contaminate groundwater. In order to evaluate the potential impacts on landfill, the results of the TCLP leaching

test were compared to the TC listing of 5 mg/L for both As and Cr, respectively, while the results of the WET leaching tests were compared to the STLC levels of 5, 5, and 25 mg/L for As, Cr, and Cu, respectively.

Table 4.3 Fractions of arsenic, chromium, and copper extracted from CCA-treated wood and ash from burning CCA-treated wood samples using the TCLP and WET

Samples	Sample ID	TCLP (% of leaching)			WET (% of leaching)		
		As	Cr	Cu	As	Cr	Cu
CCA-treated hardwood outer 6/10"	f	5.97	0.52	1.98	46.3	9.37	68.2
CCA-treated hardwood cross section	g	8.94	0.70	5.34	71.4	22.1	93.4
CCA-treated softwood outer 6/10"	h	1.27	0.10	0.84	35.0	5.78	59.0
CCA-treated softwood cross section	i	9.66	0.86	5.70	60.6	22.5	34.4
Weathered CCA-treated wood Cross section	j	2.87	0.15	3.69	7.83	1.22	4.23
Ash from CCA-treated wood	k	2.50	30.8	1.34	18.5	97.0	14.6

The results from both tests indicated that both the outer 6/10" layer and cross-sections of the hardwood samples leached arsenic concentrations that were higher than the TC and STLC limits. For the softwood samples, only the outer 6/10" layer sample leached an arsenic concentration during the WET test that was higher than STLC limit. All three metals that leached from the ash samples were much higher than the TC and STLC limits. It can be concluded from this study that the disposal of CCA-treated wood must include the appropriate control of arsenic to

prevent groundwater contamination. However, according to the results obtained, not all CCA-treated woods can be clearly classified as hazardous waste. More CCA-treated samples should be collected and put through leaching tests in order to gain more information to plan proper means for disposing of CCA-treated woods.

With regard to ash from burnt CCA-treated waste, it is clearly illustrated from the TCLP and WET tests that this waste is classified as a hazardous waste. The results provide evidence that ash from CCA-treated wood requires highly stringent disposal regulations. The CCA-treated wood must be separated from the wood used in an energy recovery plant and must not be used as a household firewood in order to prevent groundwater contamination from the land disposal of this type of ash.

4.2 Lysimeter tests

4.2.1 Simulated added rainfall

The lysimeter tests were operated indoors at the Department of Environmental Engineering, Faculty of Engineering, Chiang Mai University over a period of 180 days. Distilled water with an amount equal to the daily recorded rainfall from May 2005 to October 2005 of Chiang Mai, Thailand, was fed to every lysimeter once a day. Figure 4.4 shows the daily amount of water added to the lysimeter. The range of simulated rainfall added each day was in the range of 3.24 mL to 2.24 L, and the total amount of water added to each lysimeter was 36.15 L (1116 mm). The highest amount of simulated rainfall added to each lysimeter occurred in the fifth month; it was 14.13 L.

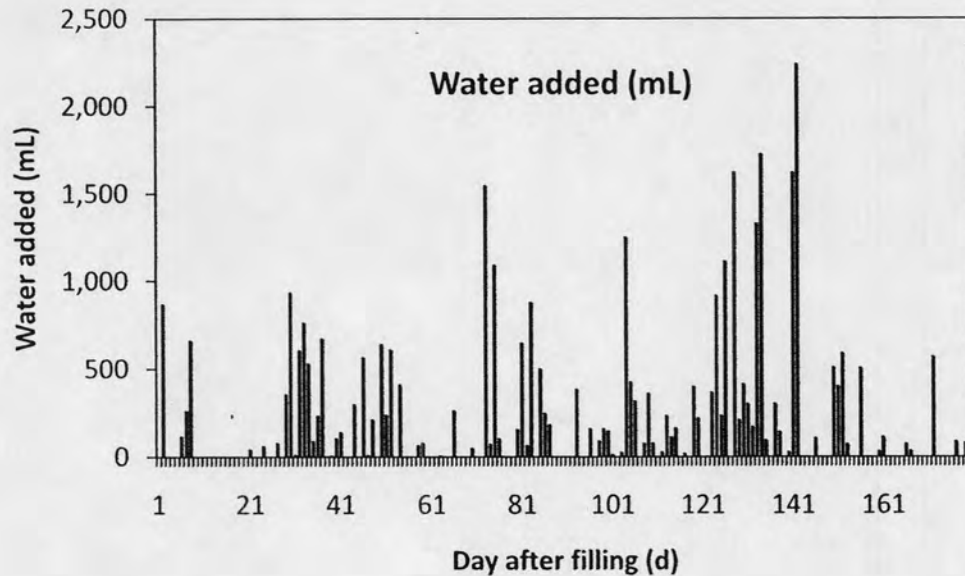


Figure 4.4 Daily amount of water added to each lysimeter

4.2.2 Leachate generation

The leachate generation results from each lysimeter are presented in Appendix C and Figure 4.5 while the cumulative leachate quantities are shown in Figure 4.6. The cumulative amounts of leachates generated from Lysimeter Nos. 1-6 were 26.6, 25.7, 26.5, 26.3, 32.8, and 32.8 L, respectively.

The cumulative leachate quantities from Lysimeter Nos. 1 and 2, which contained 100% wood were nearly the same and both of them absorbed fair amounts of the water added throughout the experiment. In the first month of the experiment, no leachate was generated from Lysimeter Nos. 3 and 4 due to the high absorption capacity of the gypsum drywall filled in these two lysimeters. The leachate amounts generated from Lysimeter Nos. 5 and 6 were the largest due to the higher moisture contents of the MSW placed in these two lysimeters.

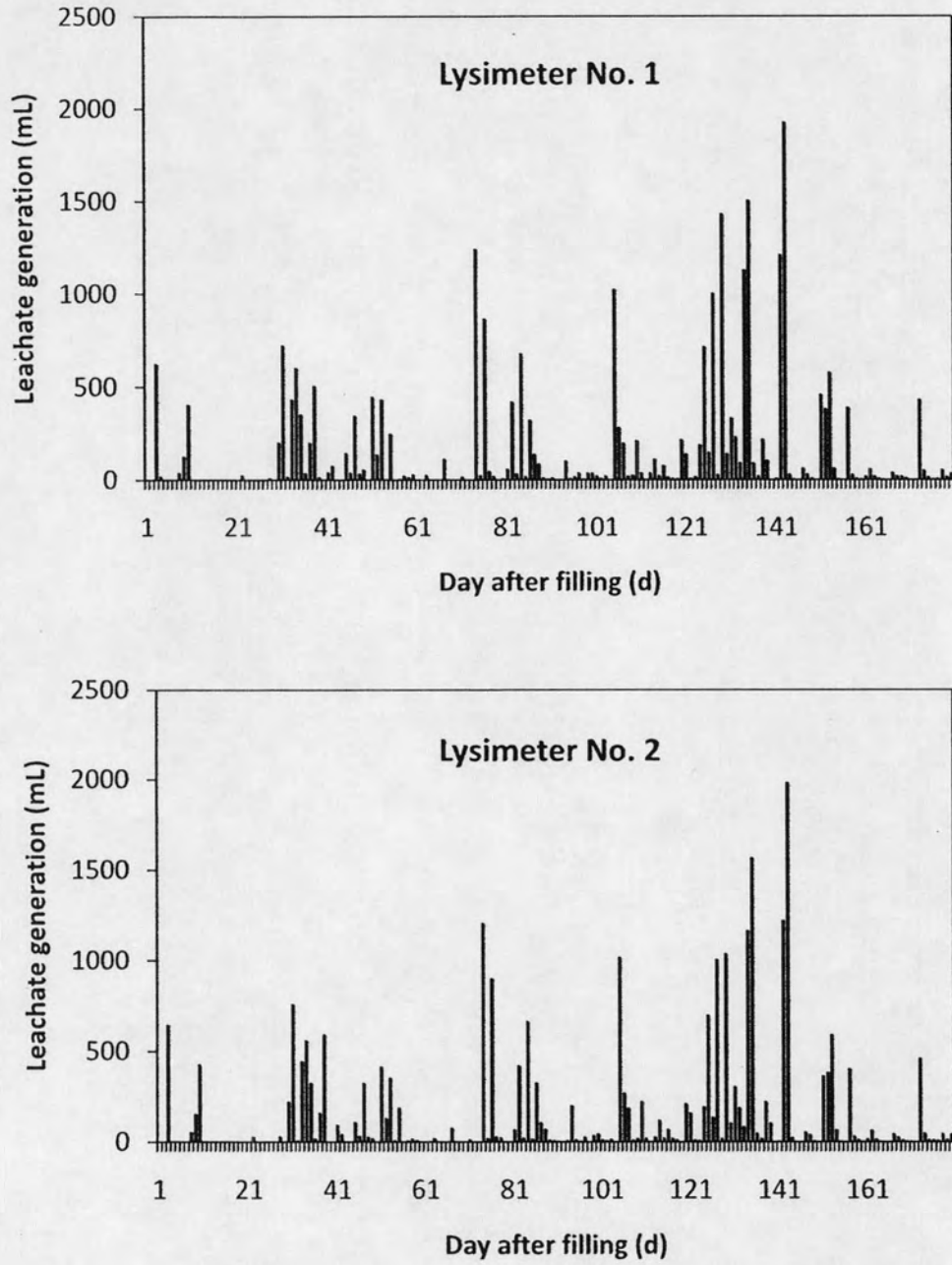


Figure 4.5 Leachate amounts generated from each lysimeter

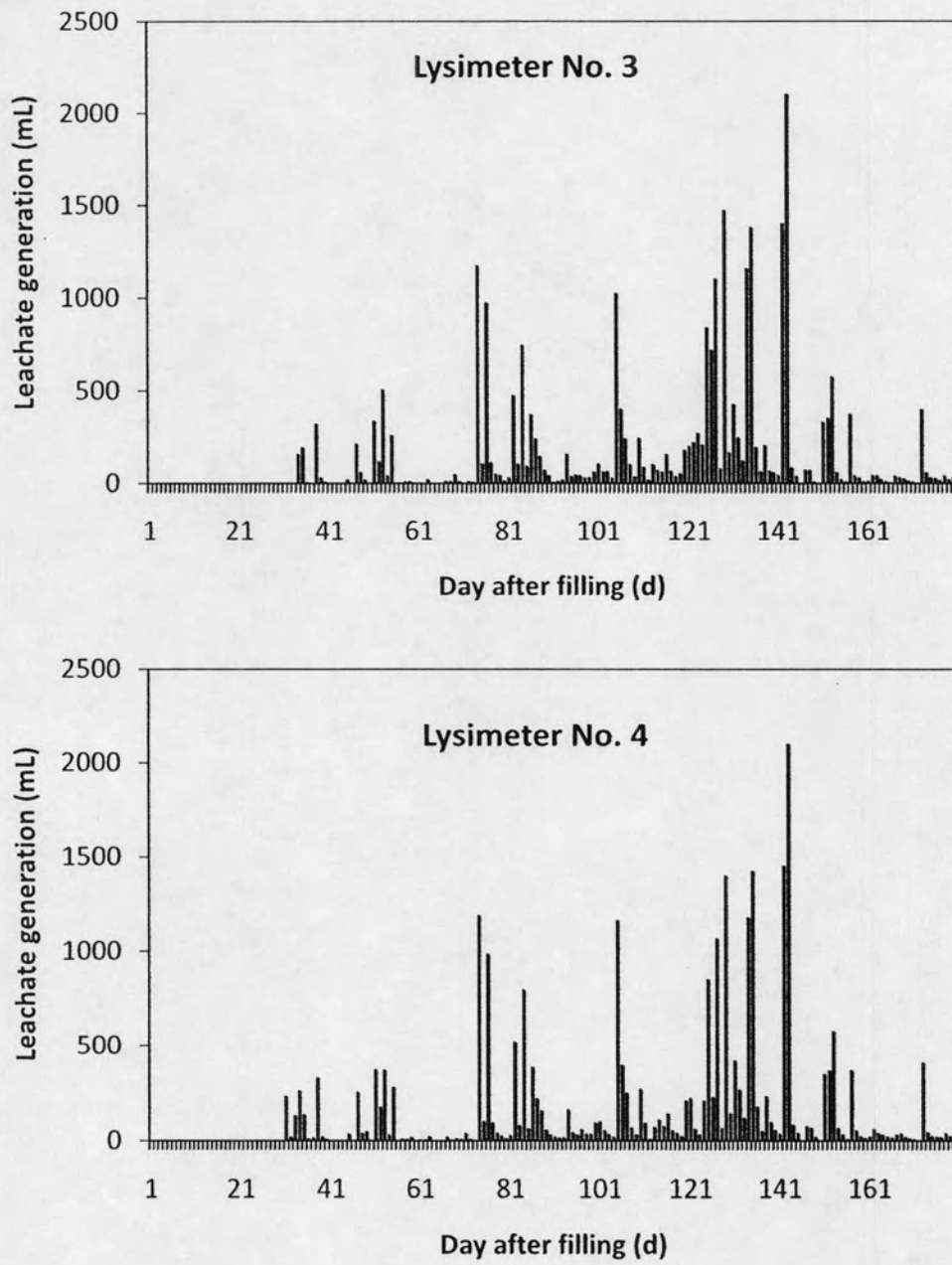


Figure 4.5 Leachate amounts generated from each lysimeter (continued)

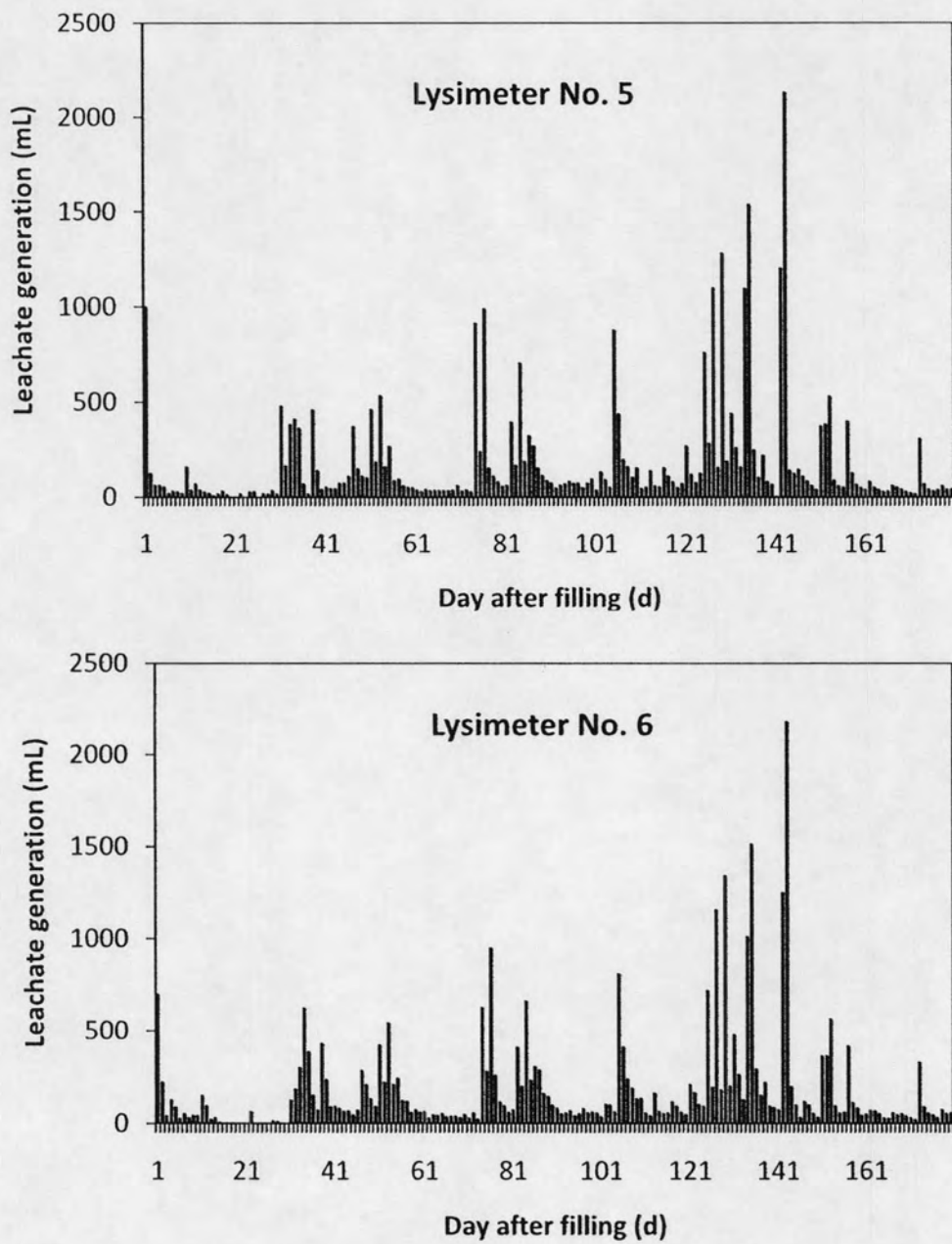


Figure 4.5 Leachate amounts generated from each lysimeter (continued)

However, according to a statistical analysis using a one-way ANOVA at 95% confidence intervals, it was found that the amounts of leachate generated from Lysimeter Nos. 1, 2, 3, 4, 5, and 6 were not significantly different ($P>0.05$). For more details, see Appendix D.

The colors of the leachate generated from the six lysimeters are presented in Figure 4.7. The leachate from Lysimeter No. 1 had quite a clear brown color in the first month and after that the leachate became turbid brown in the second month and stayed that way until the rest of the experiment due to the leaching out of the wood particles. On the other hand, the leachate from Lysimeter No. 2 had a turbid green color during the first month due to the leaching out of the CCA solution residue from the wood surface. It should be noted that the CCA solution has a green color. In the second month, it became quite clear and then it turned brown in the third month and remained that color until the end of experiment. Lysimeter Nos. 3 and 4, generated leachates with nearly the same appearance: clear during the beginning period and yellow-brown in color during the later period. The leachates generated from Lysimeter Nos. 5 and 6 had a dark brown color due to the anaerobic decomposition of the organic matter, and the color became lighter during the last month of the experiment.

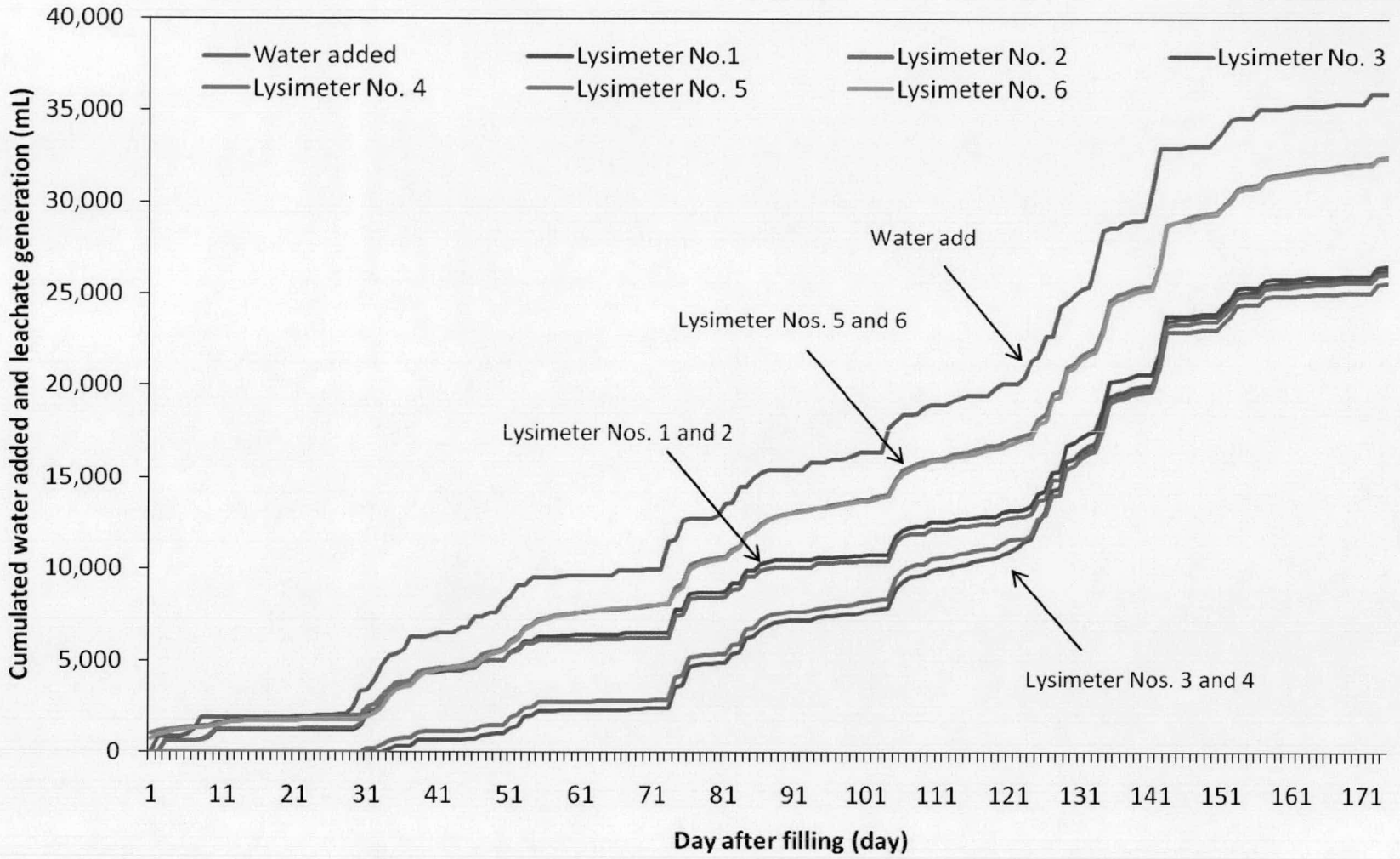
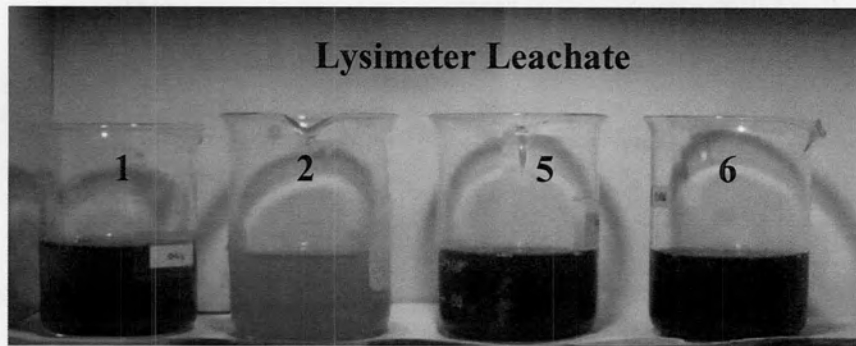
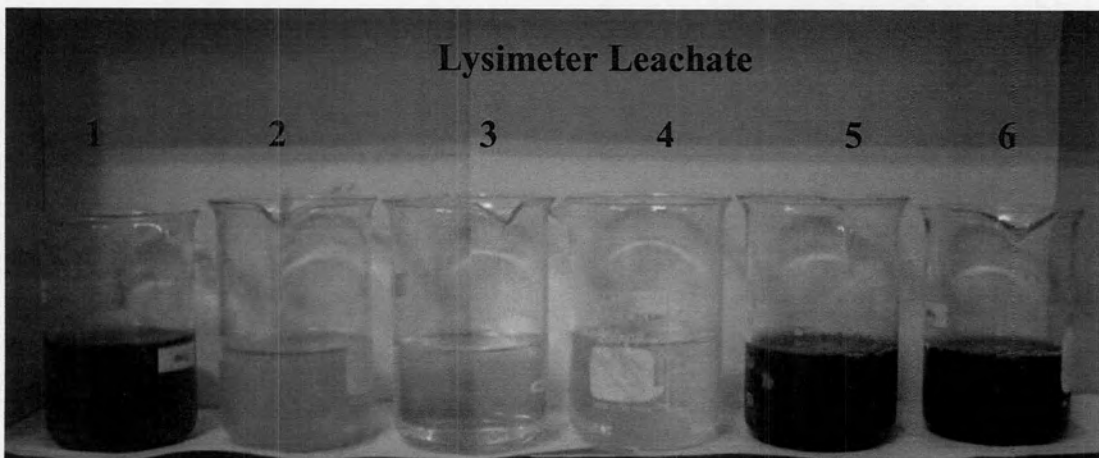


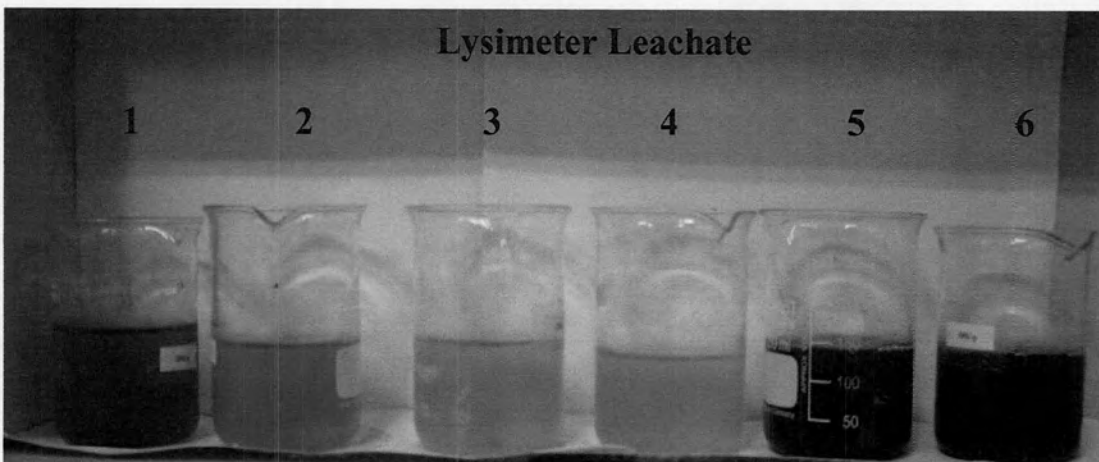
Figure 4.6 Cumulative water added and the leachate quantities (mL)



(a) 1st month

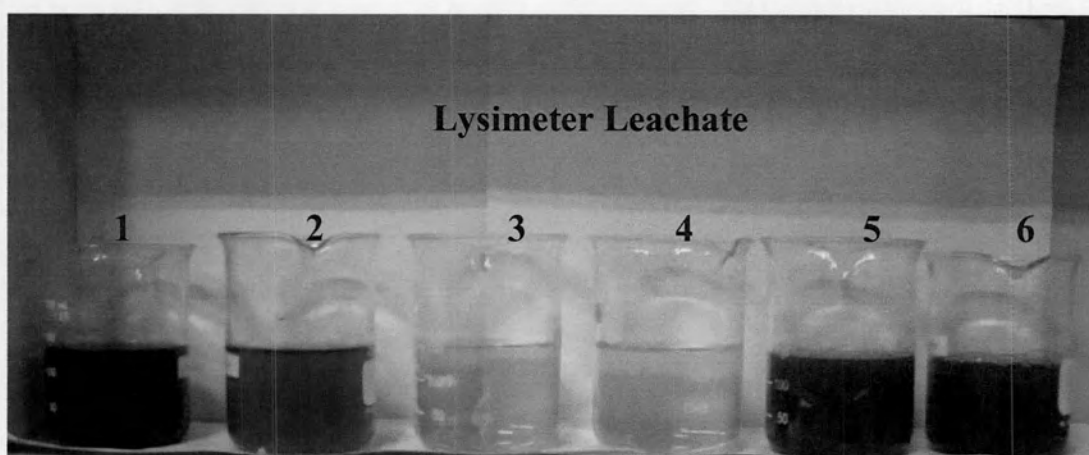


(b) 2nd month

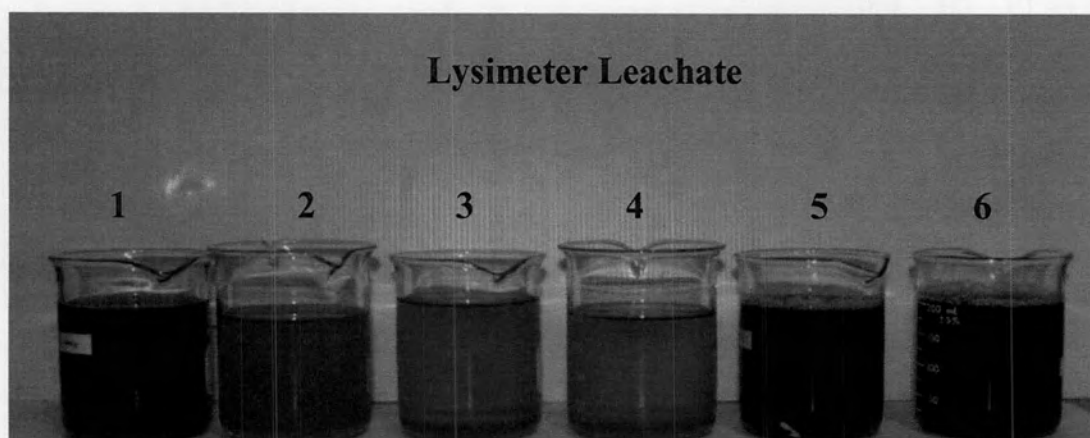


(c) 3rd month

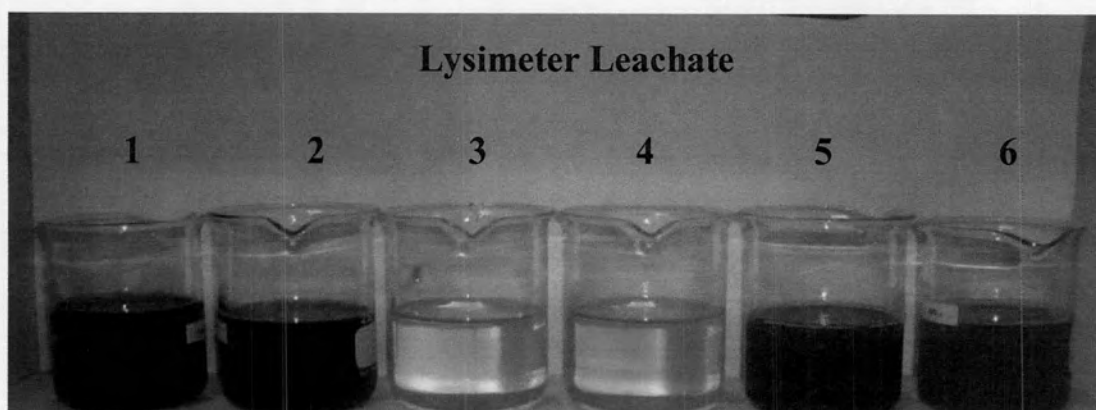
Figure 4.7 Color of leachate generated each month



(d) 4th month



(e) 5th month



(f) 6th month

Figure 4.7 Colors of leachate generated each month

4.2.3 Leachate characteristics

4.2.3.1 Monofill lysimeters (Lysimeter Nos. 1 and 2)

Lysimeter Nos. 1 and 2 were filled with untreated wood (100%) and CCA-treated wood (100%), respectively. The leachate samples from both lysimeters were analyzed for pH, oxidation-reduction potential (ORP), conductivity, total organic carbon (TOC), dissolved organic carbon (DOC), arsenic, chromium, and copper values through to the end of the experiment. The results obtained are shown in Appendix E and Figure 4.8.

The pH levels of the leachates from both lysimeters were found to be in range of 5.17 to 7.56, and were not significantly different at a 95% confidence interval ($P > 0.05$). However, from the middle of the fifth month, the pH decreased slightly overtime. Similarly, Jambeck (2006) reported that the pH in the wood filled lysimeters tended to decrease slightly overtime (average 5.6-5.8) and Jang (2000) observed an average pH of 4.4 in an untreated Southern Yellow Pine wood filled lysimeter. This might be because of the dissolution of the large organic molecules from the wood, which created an organic acid in the leachate.

The conductivity of the leachate from both lysimeters slightly increased overtime. The average level of conductivity in the leachate generated from Lysimeter No. 2 (0.58 mS/cm) was higher than the average level of conductivity in the leachate generated from Lysimeter No. 1 (average 0.36 mS/cm). CCA-treated wood typically contributes more to the dissolution ions in solution than untreated wood. This result was consistent with the results of Jambeck (2006). In addition, the conductivities from both lysimeters were significantly different, at a 95% confidence interval ($P < 0.05$).

The average values of ORP from Lysimeter Nos. 1 and 2 were approximately 161.7 and 233.7 mV, respectively. The ORP results of both Lysimeter remained in the oxidation condition throughout the experiment of six months, which corresponded to the study of Jambeck (2006). A statistical analysis shows that the average level of leachate ORP from Lysimeter No. 2 was significantly higher than that of Lysimeter No. 1 ($P < 0.05$). The harder degradation of the CCA-treated wood in

Lysimeter No.2 and resulted in the lower biodegradation activity were the cause of this finding.

TOC and DOC contents in the leachates from both lysimeters were in the same order that illustrated that almost organic carbons were in dissolved form. TOC and DOC results of the leachate generated from both lysimeters from the middle of the fourth month increased continuously until the end of experiment. This increasing trend might indicate that the higher organic matter in the leachate from wood decomposition resulted from the higher moisture content of wood material in the later period. It was also found that the TOC and DOC of Lysimeter No. 1 were higher than the levels from Lysimeter No. 2. It might be because untreated wood decays faster than treated wood.

The three metal concentrations in the leachate from Lysimeter No. 1 were found to be below the detection limits (<0.005 mg/L for arsenic, <0.06 mg/L for chromium, and <0.05 mg/L for copper), while the average concentrations of those metals from Lysimeter No. 2 were found to be 15.67, 13.65, and 6.32 mg/L, respectively. The metal concentrations in the leachate generated from the CCA-treated wood monofill scenario, which contained only CCA-treated wood, were significantly higher than those of the leachate from the untreated wood monofill at a 95% confidence interval ($P<0.05$). The maximum concentrations of arsenic, chromium, and copper were found at 68.61, 134.25, and 48.35 mg/L, respectively. This trend was similarly found in a study by Townsend (2004). All three metal concentrations in the leachate generated from Lysimeter No. 2 were found to be very high during the first two weeks due to the leaching out of CCA residue from the wood surface. From the third to fourth month until the end of experiment, all three metal concentrations were found at high concentrations. This might be because of the dissolution of these metals from the degraded wood in the inner layer by the penetrated water.

The US EPA (1995) assumes that leachate from construction and demolition waste landfills would be diluted by at least ten times in the environment. Therefore, ten times the limited amount regulated in the Groundwater Standards for Drinking Purposes in Thailand from the Notification of the Ministry of Industrial (standards of arsenic, chromium, and copper concentrations in the groundwater for drinking purposes are 0.05, 2.0, and 1.5 mg/L, respectively)(MOI, 1997) was used to

evaluate the potential risk to humans and the environment in this study. The average concentrations of the three metals in the leachate from Lysimeter No. 2 were compared with the criteria mentioned above and it was found that the average concentration of arsenic was much higher than the criterion at 0.5 mg/L. However, the average concentrations of chromium and copper were lower than the criteria at 20 and 15 mg/L, respectively.

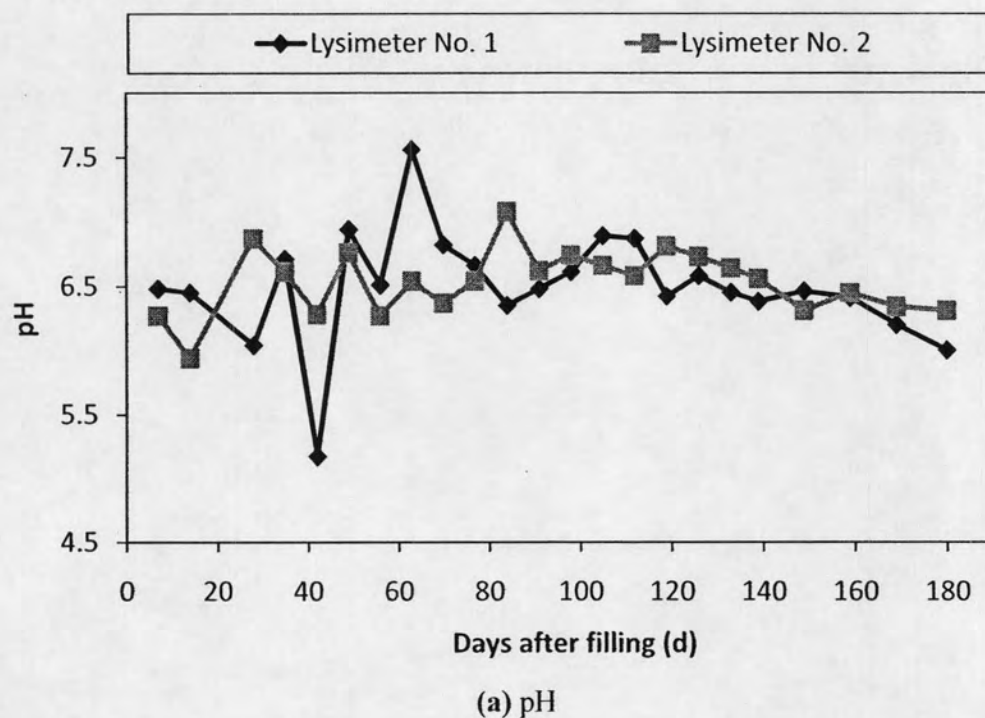
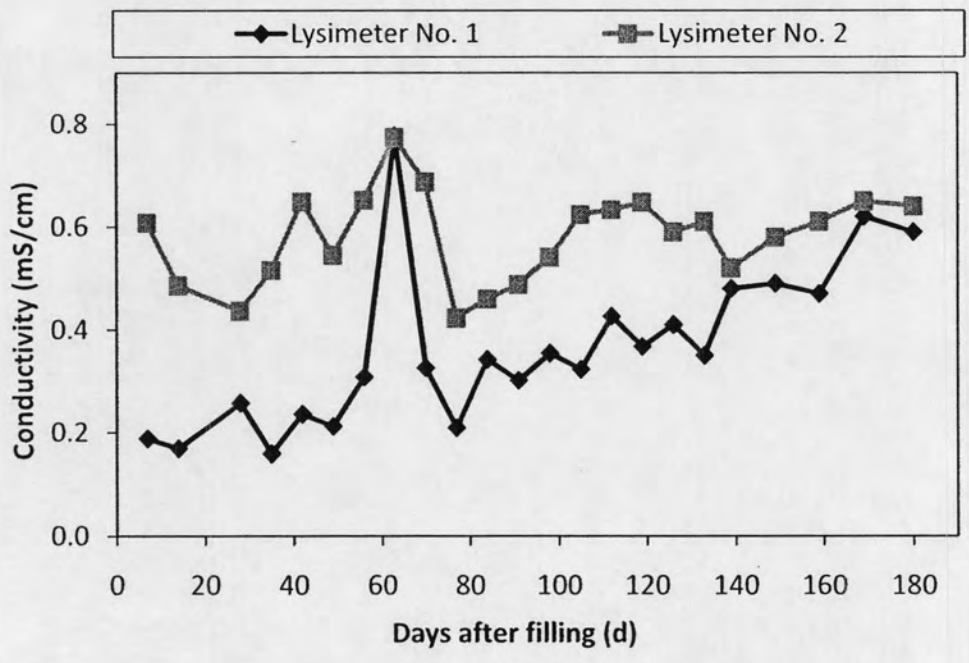
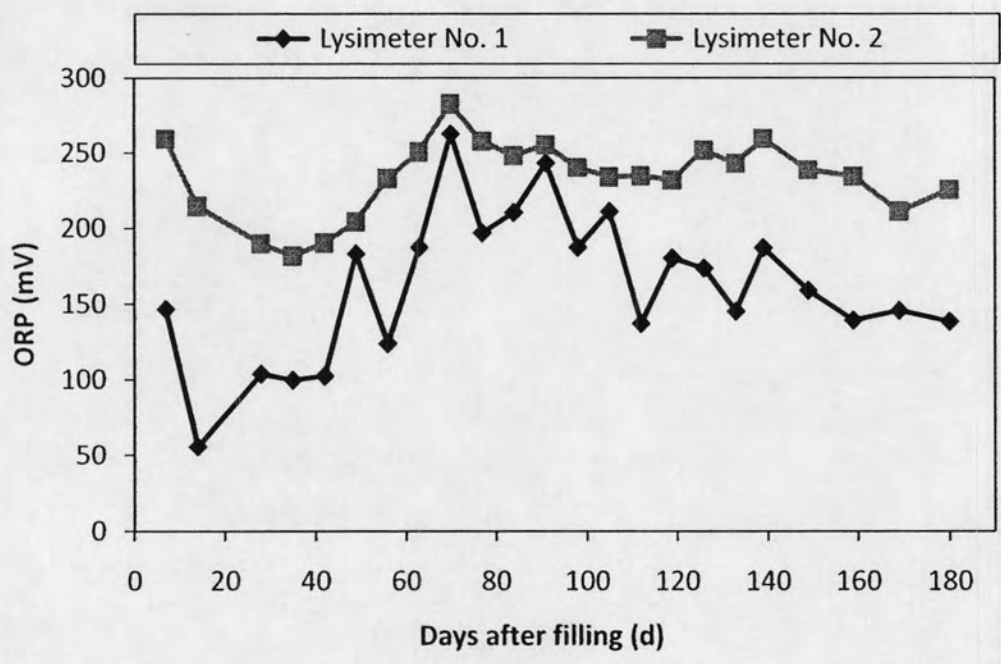


Figure 4.8 Leachate characteristic variations over time from Lysimeter Nos. 1 and 2

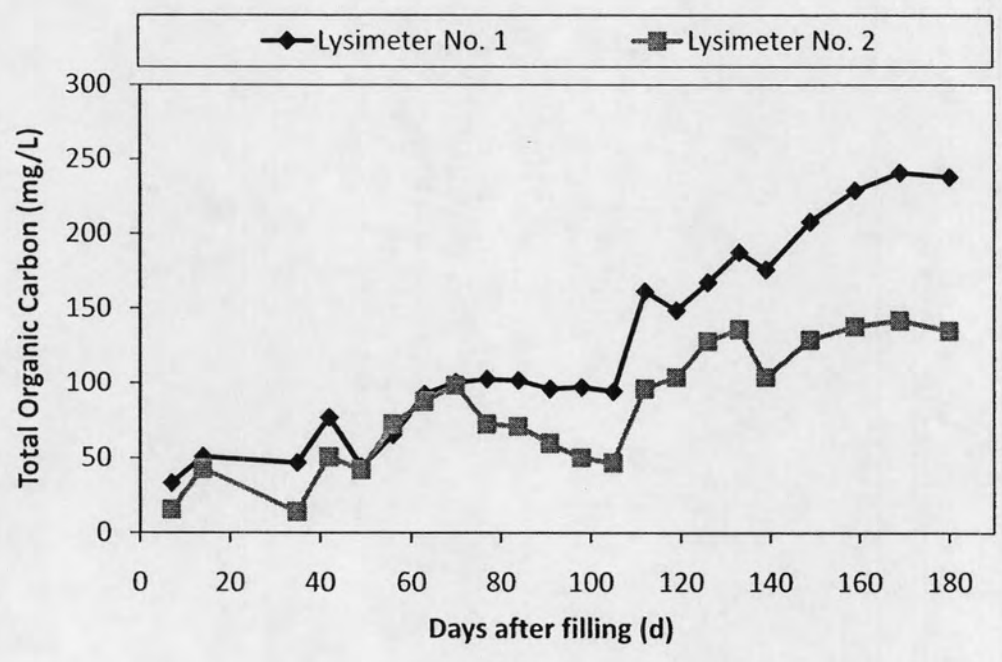


(b) Conductivity

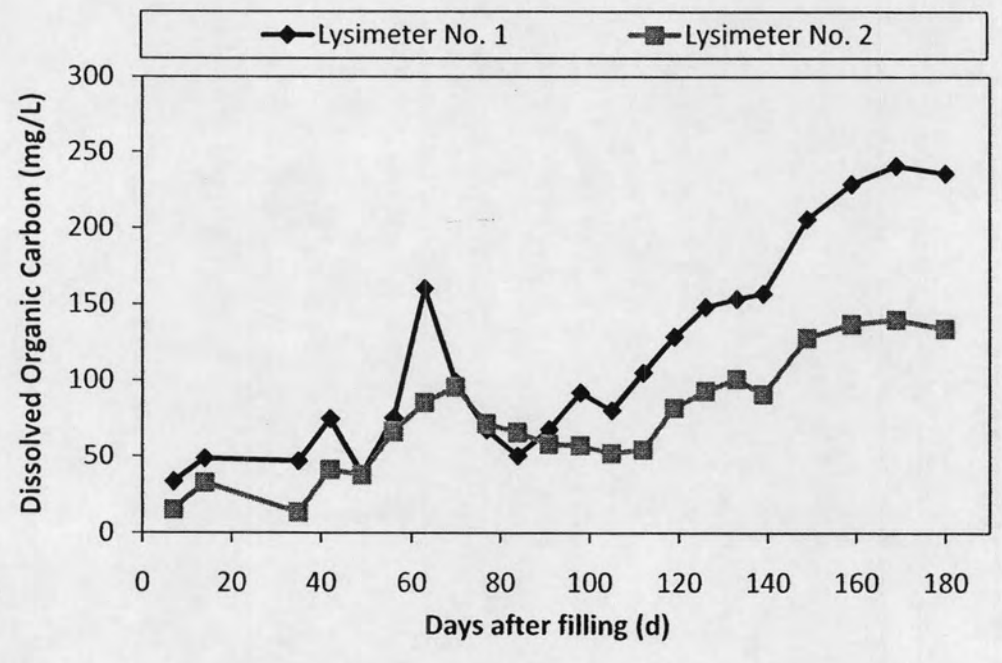


(c) ORP

Figure 4.8 Leachate characteristic variations over time from Lysimeter Nos. 1 and 2 (continued)

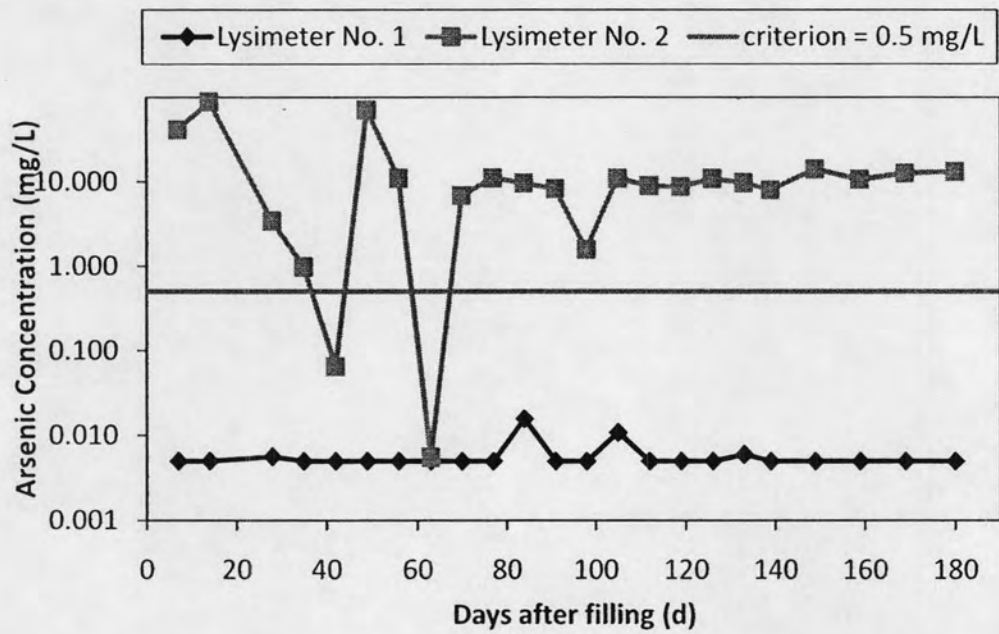


(d) TOC

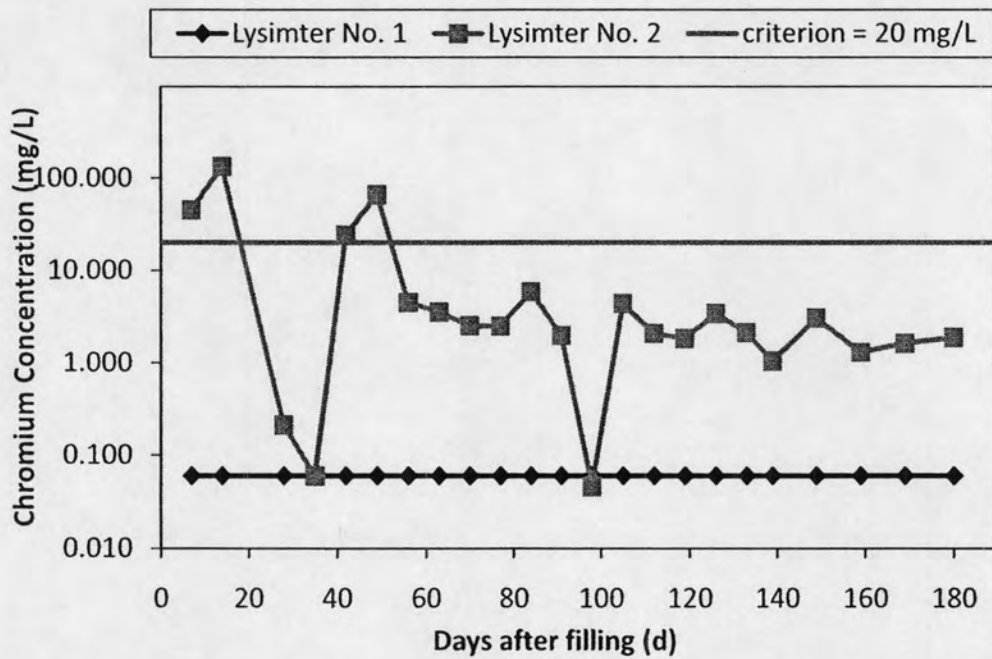


(e) DOC

Figure 4.8 Leachate characteristic variations over time from Lysimeter Nos. 1 and 2 (continued)

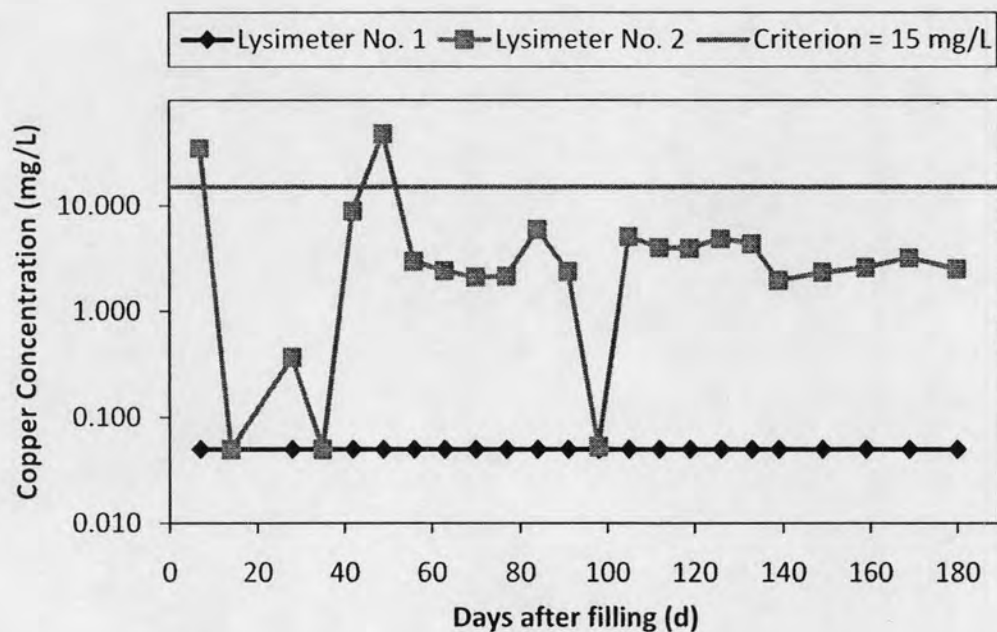


(f) Arsenic



(g) Chromium

Figure 4.8 Leachate characteristic variations over time from Lysimeter Nos. 1 and 2
(continued)



(h) Copper

Figure 4.8 Leachate characteristic variations over time from Lysimeter Nos. 1 and 2 (continued)

4.2.3.2 Construction and demolition debris lysimeters (Lysimeter Nos. 3 and 4)

The C&D debris lysimeters contained high amounts of wood. In this study, 14% of the fill in Lysimeter No. 3 consisted of wood, while the fill in Lysimeter No. 4 consisted of 7% untreated wood and 7% CCA-treated wood. The results of pH, ORP, conductivity, TOC, DOC, arsenic, chromium, and copper are shown in Figure 4.9 and Appendix E.

During the first month, no leachate was generated from lysimeter Nos. 3 and 4. Leachate was generated from the second month onwards. The pH values from both lysimeters started at around 7.0. Then, they increased to around 7.5 in the third month and remained constant until the end of the experiment. The pH values were in the same range as the pH values in the studies of Townsend (2000), Weber (2001), and Sangsuwan (2007). There was not any significant difference at a 95%

confidence interval ($P>0.05$) between the pH values from Lysimeter No. 3 and Lysimeter No. 4.

The conductivity of leachate generated from Lysimeter Nos. 3 and 4 began around 2 mS/cm, and increased continuously during the second and third months. In the fourth month, the conductivity was 3.0 to 3.5 mS/cm in both lysimeters and remained constant until the end of the experiment. The conductivity from both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$). The conductivity results were consistent with the results of Townsend's study (2000). Townsend conducted a lysimeter study with the same waste layer height as in this study. However, the values were lower than those in the study of Jambeck (2006) because the height of the experimental lysimeter of Jambeck (2006) was 6.1-meter, 4 times higher than the height of the waste in this study. Townsend et al. (2000) also reported that the conductivity varies with the height of the waste.

The ORP results show the oxidation condition in both lysimeters (averages: 186 mV for Lysimeter No. 3 and 179 mV for Lysimeter No. 4). The ORP began around 170 mV and then increased overtime until around day 80. After that, the ORP decreased to be around 120 mV until the fourth month. Then the ORP started to increase again to 170 mV in a few weeks and remained constant until the end of experiment. This variation might be related to the variations in the simulated rainfall that was added to the lysimeters. During the filling age of 105-120 days, the amount of simulated rainfall was small and after that, the amount of simulated rainfall was extremely large. The large amount of simulated rainfall in the later period may have increased the ORP in the leachate. The range of ORP in both lysimeters was in the same order and this range was consistent with the ORP results in the study of Sangsuwan (2007), who conducted a lysimeter study of demolition waste. The ORP from both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$).

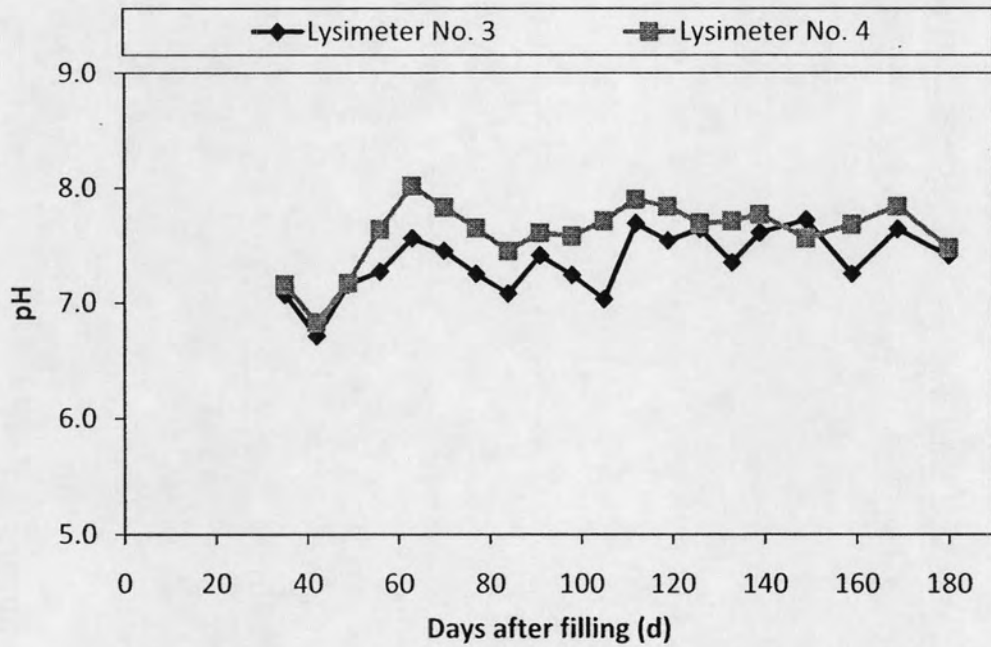
TOC and DOC contents in the leachates from both lysimeters were in the same order; this illustrated that most of the organic carbons were in the dissolved form. The TOC and DOC contents from Lysimeter Nos. 3 slightly decreased while these contents from Lysimeter No. 4 increased in the second month of the experiment. Furthermore, in the third month, the TOC and DOC became constant, around 50-100 mg/L, in both lysimeters and then showed a slightly increasing trend

in the last month of the experiment. As the result, Lysimeter Nos. 3 and 4 might have been in the initial aerobic phase and transition phase of degradation in a C&D landfill (Jang, 2000). The results of TOC were consistent with those in the study of Sangsuwan (2007).

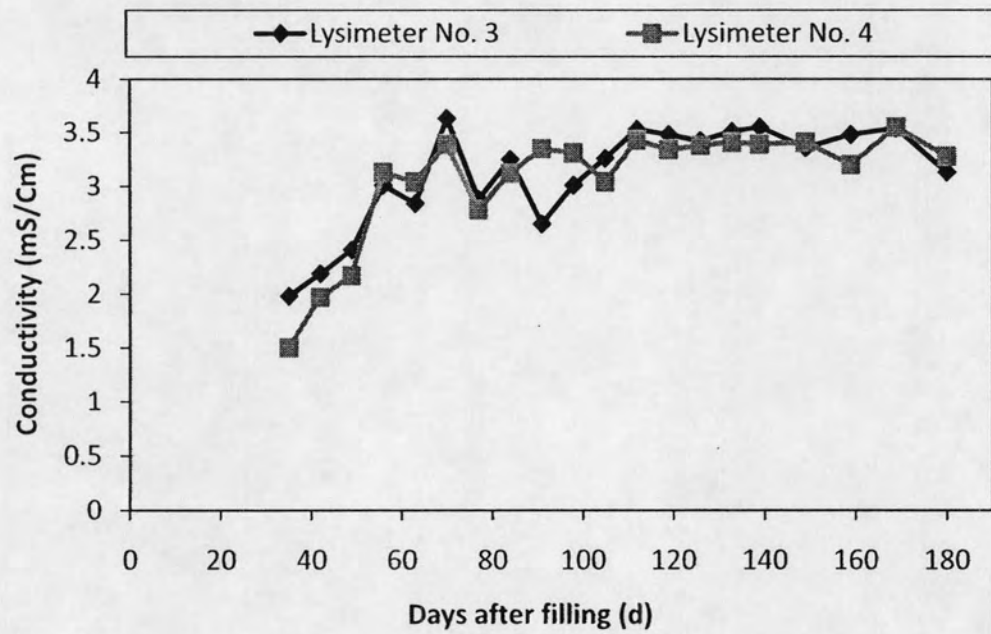
Three of the metal concentrations in the leachate from Lysimeter No. 3 were found to be near or below the detection limits (<0.005 mg/L for arsenic, <0.06 mg/L for chromium, and <0.05 mg/L for copper), while the average concentrations of arsenic, chromium, and copper from Lysimeter No. 4 were found to be 0.53, 0.26, and 0.16 mg/L, respectively. An interesting trend for arsenic appeared in Lysimeter No. 4, which contained 7% of CCA-treated wood by mass. On day 105 a low arsenic concentration leached out when a low amount of leachate was generated. After that, an increasing trend of arsenic was found until the end of the experiment. This may have occurred due to the active biological processes in the wood and the penetrated water dissolving the arsenic from the degraded wood in the inner layer. Chromium concentrations in Lysimeter No. 4 followed a different trend from arsenic. Chromium was present in high concentrations during the third to fourth months of the experiment and then showed an increasing trend again at the end of the experiment. Copper leached in the range of <0.05 to 0.89 mg/L. The low concentration of copper was detected because copper was precipitated as a sulfide precipitate in the waste layer (Townsend, 2000).

Furthermore, all three metals' average concentrations in the leachate from the C&D debris waste with CCA-treated wood were significantly higher than those of leachate from the C&D debris waste with untreated wood at a 95% confidence interval ($P<0.05$).

The average concentration of the three metals in the leachate from Lysimeter No. 4 were compared with the criteria which is ten times the limited amount regulated in Groundwater Standards for Drinking Purposes in Thailand from the Notification of the Ministry of Industrial (MOI, 1997) and it was found that only the arsenic concentration surpassed the criterion which is 0.5 mg/L for arsenic. On the other hand, the average concentrations of chromium and copper did not exceed the criteria at 20 and 15 mg/L, respectively.

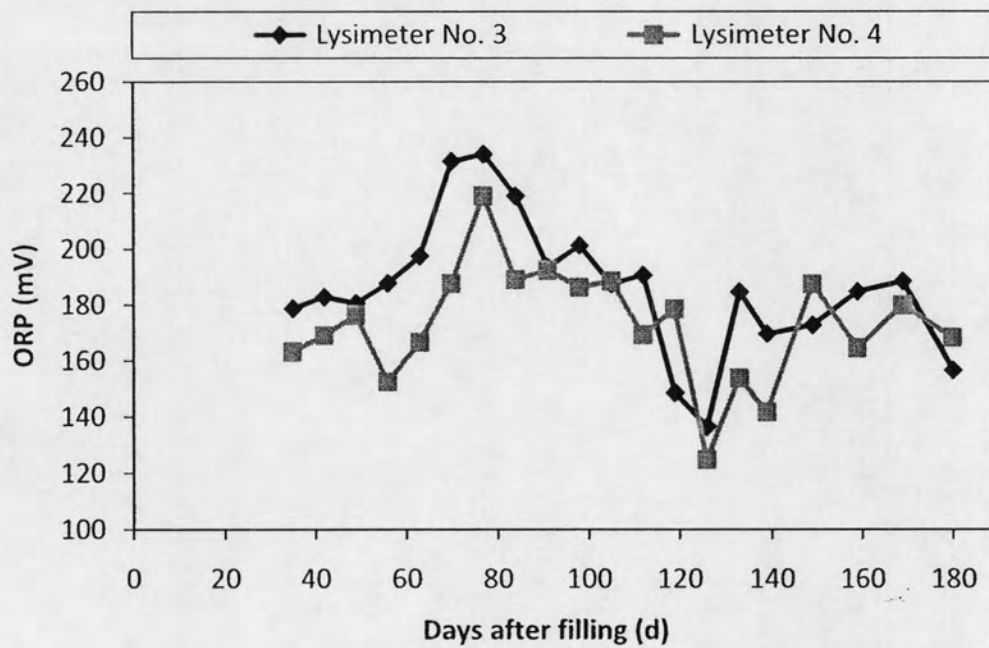


(a) pH

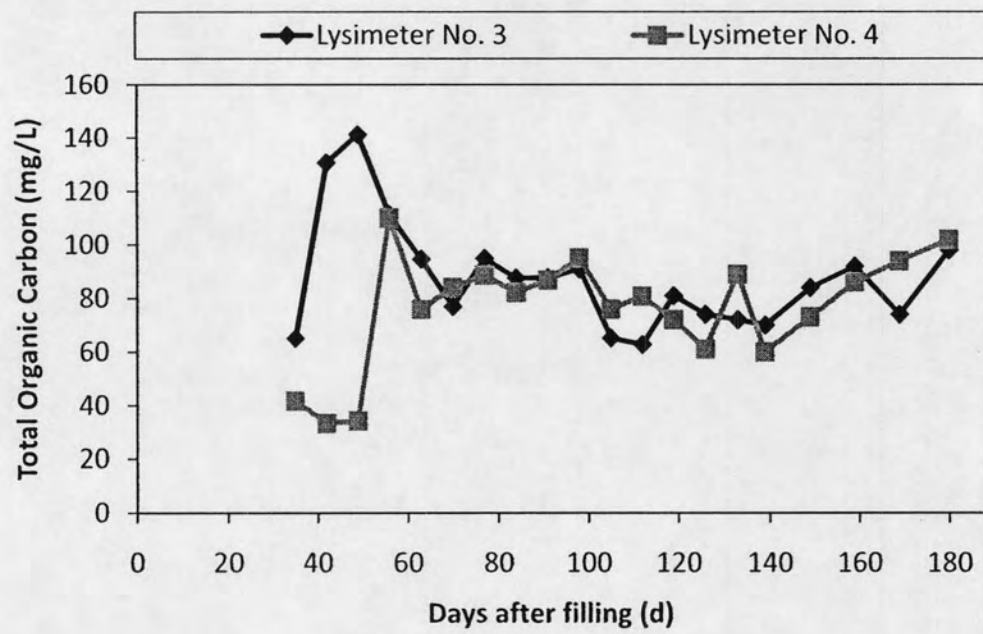


(b) Conductivity

Figure 4.9 Leachate characteristic variations over time from Lysimeter Nos. 3 and 4

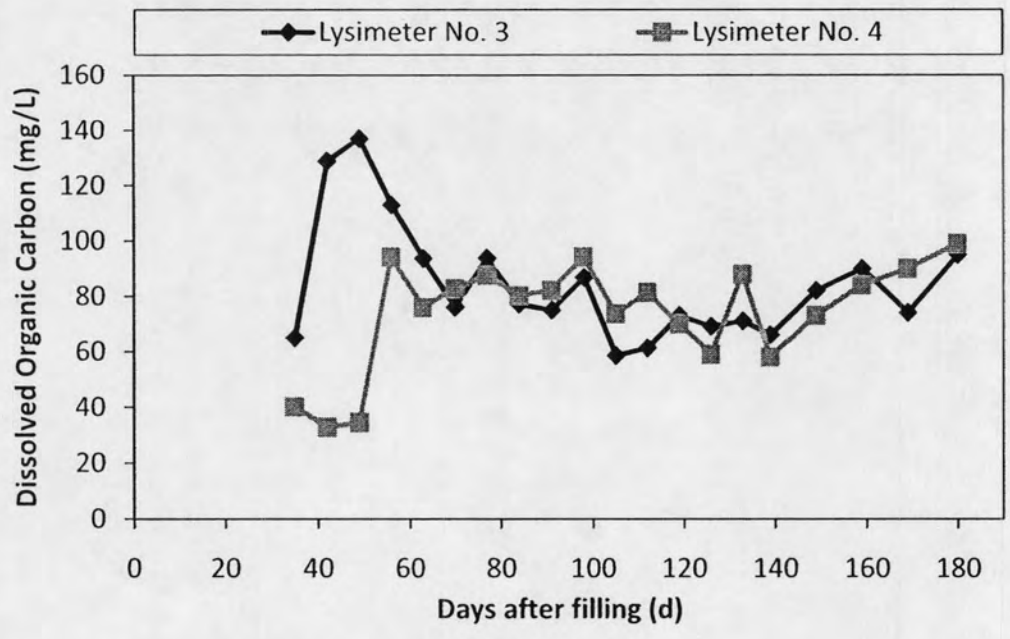


(c) ORP

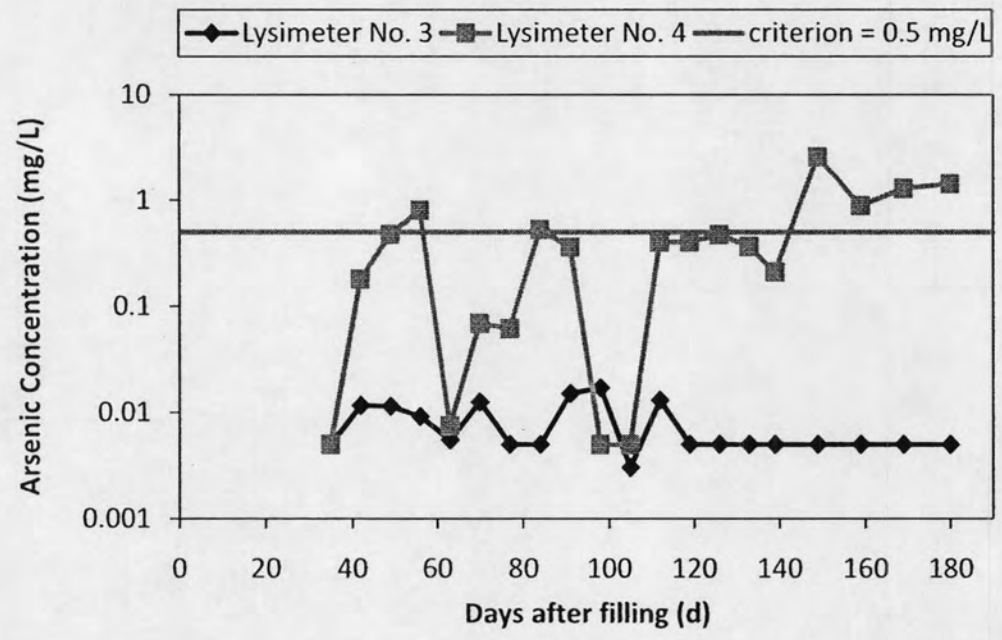


(d) TOC

Figure 4.9 Leachate characteristic variations over time from Lysimeter Nos. 3 and 4 (continued)

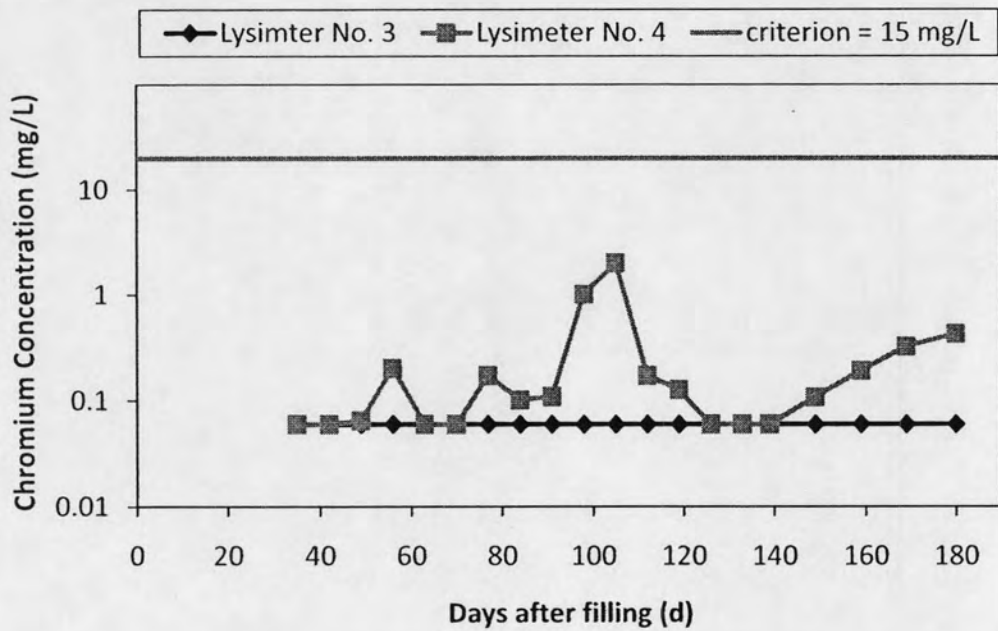


(e) DOC

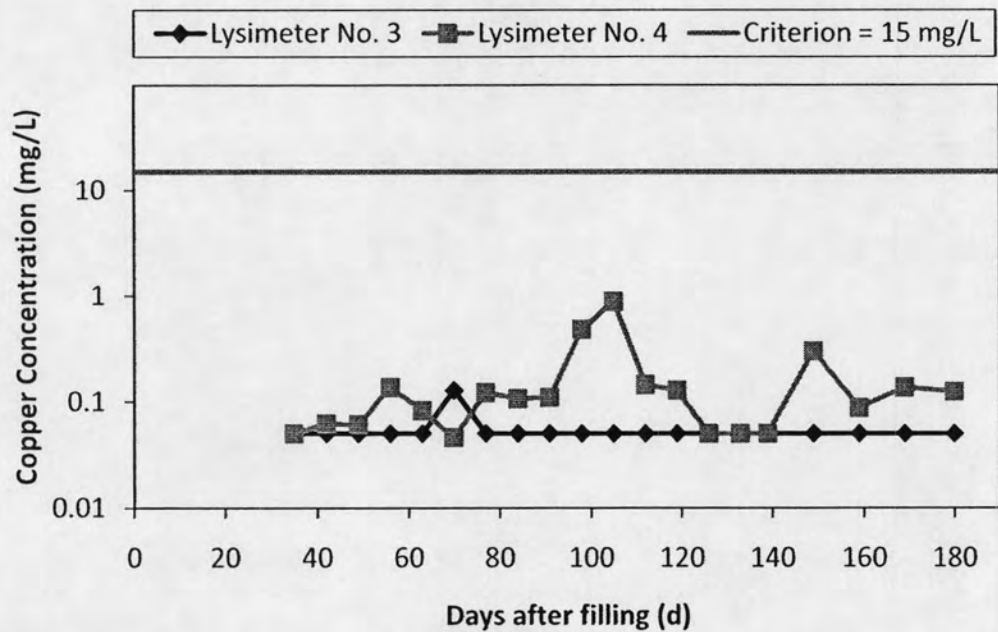


(f) Arsenic

Figure 4.9 Leachate characteristic variations over time from Lysimeter Nos. 3 and 4 (continued)



(g) Chromium



(h) Copper

Figure 4.9 Leachate characteristic variations over time from Lysimeter Nos. 3 and 4 (continued)

4.2.3.3 Municipal solid waste lysimeters (Lysimeter Nos. 5 and 6)

Lysimeter Nos. 5 and 6 represented MSW landfill scenarios. Lysimeter No. 5 was the control lysimeter, which had 2% of untreated wood, while Lysimeter No. 6 had 2% of CCA-treated wood by mass. The results of pH, oxidation-reduction potential (ORP), conductivity, total alkalinity (TA), volatile acid (VA), total organic carbon (TOC), and dissolved organic carbon (DOC), and arsenic, chromium, and copper are illustrated in Figure 4.10 and Appendix E.

The pH levels from both lysimeters ranged from 3.7 to 6.8. The MSW lysimeters began with a low pH (3.7), assumedly the result of being in the hydrolysis and fermentation phase of the biodegradation process (Whittleton, 2004). After the first month, the pH increased to approximately 5.5 and stabilized during the third to fourth month period in both lysimeters. In the last two months, pH slightly increased to approximately 6.0. The pH results were consistent with those in the studies of Karnchanawong et al. (2004) and Limpiteprakan (2005), which were both lysimeter studies of Chiang Mai MSW. From the statistic analysis, the pH results of both lysimeters were not significantly different at a 95% of confidence interval ($P>0.05$).

Conductivity was observed in the range of 10.2 to 24.1 mS/cm. It was found that conductivity increased from around 13.7 to 24.1 mV in the first month and became constant during the second to third month. After day 70, the conductivity variations in both lysimeters followed the same trend: they slightly decreased from 24.1 to around 14.5 mV. It seems that, the conductivity of the leachate from Lysimeter No. 6 (MSW with 2% CCA-treated wood) was higher than Lysimeter No. 5 (MSW with 2% untreated wood). However, the results from the statistic analyses indicated that the conductivity values of both lysimeters were not significantly different at a 95% of confidence interval ($P>0.05$). The range of conductivity of the MSW lysimeters was the same as those in the studies of Jamback (2004) and Limpiteerakan (2005).

It was observed that the ORP levels for both lysimeters varied in the range of 20-140 mV during the first to third months and then slightly decreased in the leachates to near the reducing condition at around 7 mV at the end of the experiment. This result was different from the study of Jamback (2004) who conducted a lysimeter study and reported that almost all ORP values were in the reducing condition. The higher lysimeters in Jamback's study could have caused the result in the higher reduced condition. The results from the statistical analyses indicated that

the conductivity values of the leachates from both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$).

The TA began to reach their maximum concentrations around 13,000 mg/L in both lysimeters during the first month and then decreased to their minimum concentrations around 3,000 mg/L in Lysimeter No. 5 and 6,000 mg/L in Lysimeter No. 6 during the second month, and then increased to around 12,000 mg/L in Lysimeter No. 5 and 9,000 mg/L in Lysimeter No. 6. Then, the TA continued to decrease gradually until the end of the experiment. The result was the same as that of the study of Jamback (2004) within the same time period of the experiment. The TA concentrations of both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$).

The VA of the leachates from both lysimeters presented its lowest concentration at around 2,350 – 2,830 mg/L, and then the VA concentration increased rapidly to around 45,000 mg/L in the beginning of the second month. After that, the VA concentration decreased over time until the end of the experiment. The high concentration of VA investigated in this experiment can be used to indicate that the biological phase in this study occurred during the acidogenic phase. This result is consistent with the results obtained by Karnchanawong et al. (1994 and 2004) who investigated the leachate and gas generation from a batch lysimeter filled with Chiang Mai MSW. They concluded that the hydrolysis phase covered two months and the methane phase started after one to two years. The concentrations of VA from both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$).

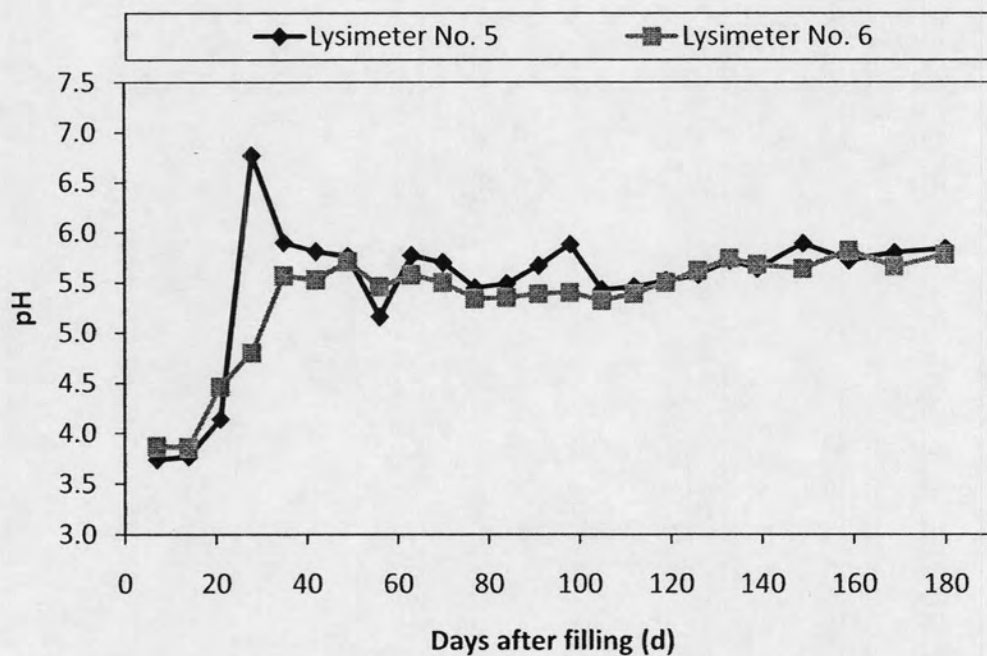
The TOC was in the range of 28,500 to 9,310 mg/L and the DOC was found to be in the range of 25,124 to 9,000 mg/L. The TOC and DOC contents in the leachates from both lysimeters were in the same order which illustrated that almost all organic carbons were in the dissolved form. A decreasing trend was found during the second to third months until the end of the experiment, which was the same trend found in the study of Limpiteeprakan (2005). From the statistic analysis, the TOC and DOC results from both lysimeters were not significantly different at a 95% confidence interval ($P>0.05$).

Arsenic was found in higher concentrations in the leachate from Lysimeter No. 6 in comparison with Lysimeter No. 5. When the concentration of arsenic and the amount of leachate generated were considered, it was found that a low

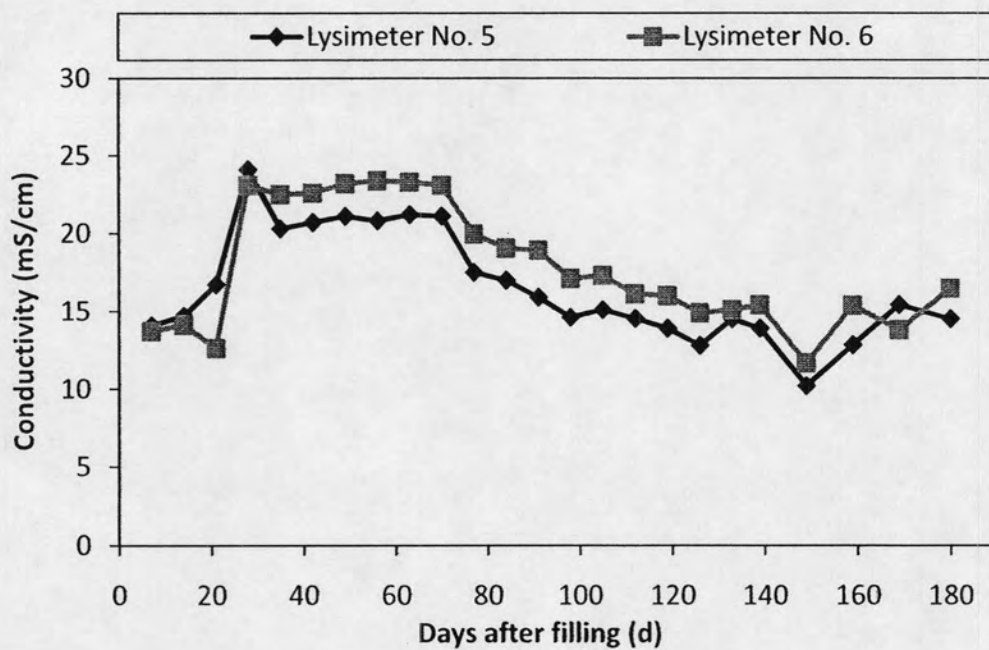
arsenic concentration leached out when a low amount of leachate was generated. An increasing trend of arsenic began at day 80 and continued until the end of the experiment. It might be because the wood had been biologically degraded and thus, leached out more arsenic. Almost all chromium and copper results from both lysimeters were found below the detection limits (0.06 mg/L for chromium and 0.05 mg/L for copper), while the average concentrations of arsenic from Lysimeter Nos. 5 and 6 were found to be 0.01 and 1.57 mg/L, respectively. The MSW lysimeter exhibited more reducing conditions than the wood monofill lysimeters, had biological activities, and many more dissolved ions in the leachate. When CCA-treated wood leaches, the relative concentration of each metal that leaches is typically arsenic>copper>chromium (Cooper, 1991 and Highston et al., 2001). For the disposal similar to Lysimeter Nos. 1-4, the relative leaching concentration were arsenic>chromium>copper (Duestsch, 1997).

The concentrations of chromium and copper from MSW lysimeter with CCA-treated wood were not significantly higher than MSW lysimeter with untreated wood at a 95% confidence interval ($P>0.05$). However, the arsenic concentrations from MSW with CCA-treated wood lysimeter were significantly higher than those of leachate from MSW with untreated wood lysimeter at a 95% confidence interval ($P<0.05$).

In the MSW lysimeters, only the average arsenic concentration from Lysimeter No. 6 surpassed the amount that is equal to ten times the Groundwater Standard for Drinking Purposes in Thailand (criteria value for arsenic is 0.5 mg/L). On the other hand, the average concentrations of chromium and copper did not exceed the criteria at 20 and 15 mg/L, respectively.

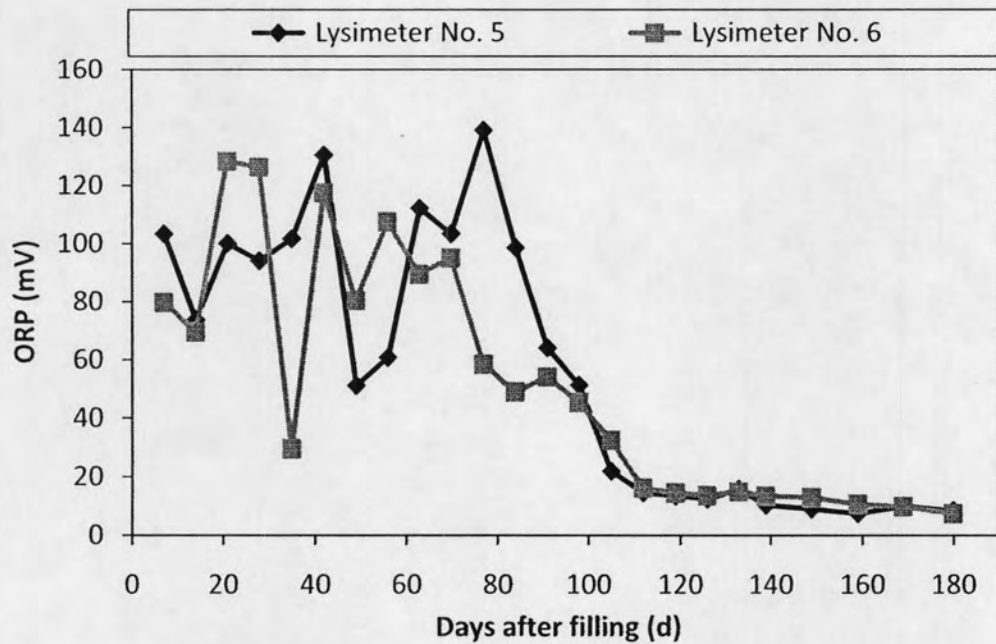


(a) pH

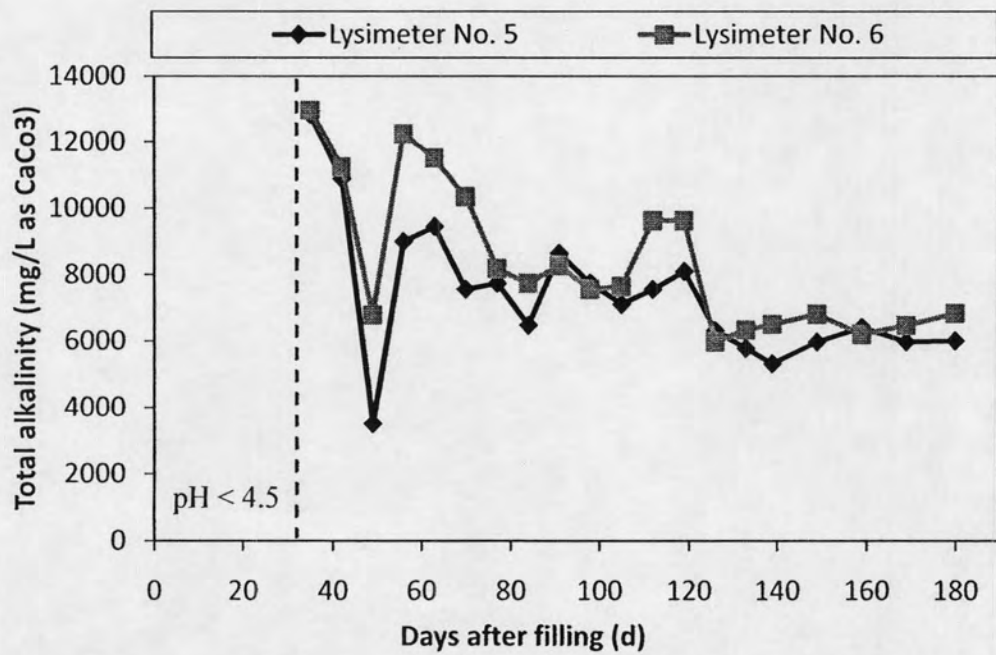


(b) Conductivity

Figure 4.10 Leachate characteristic variations over time from Lysimeter Nos.5 and 6



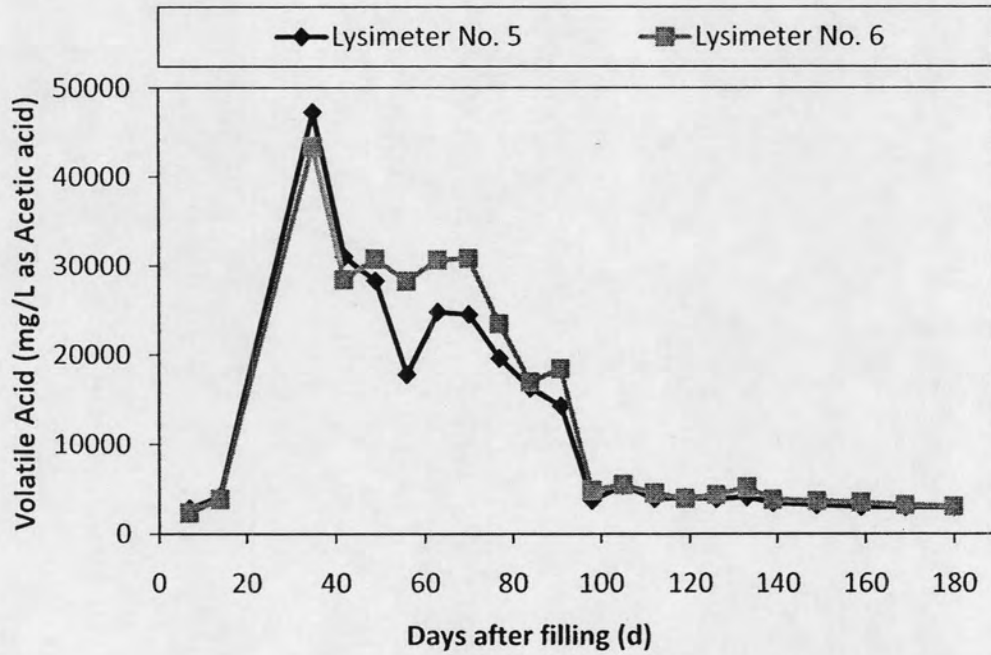
(c) ORP



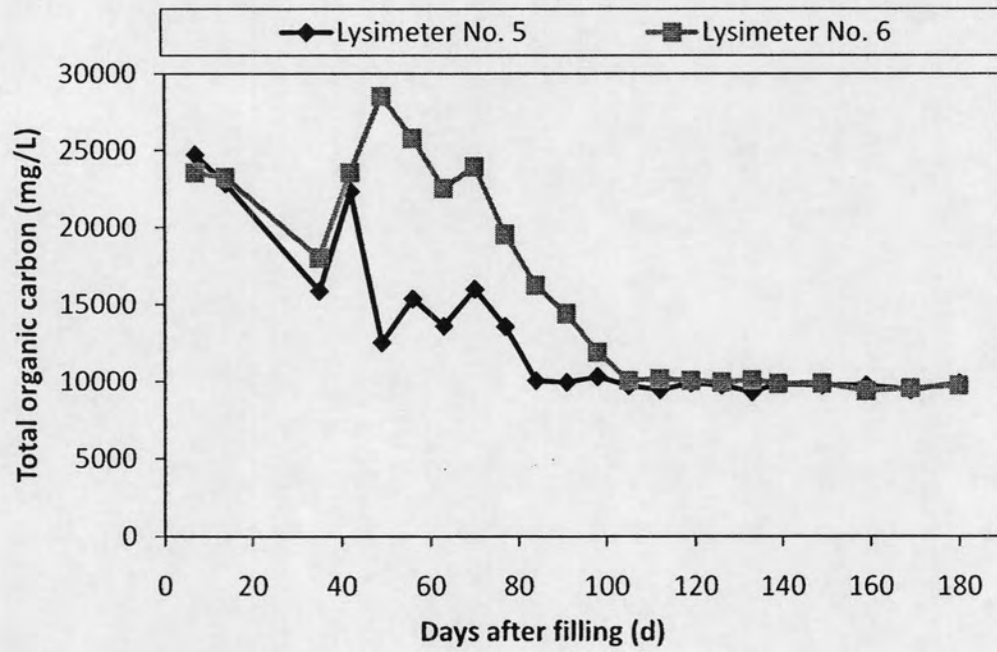
(d) Total alkalinity

Figure 4.10 Leachate characteristic variations over time from Lysimeter Nos. 5 and 6

(continued)

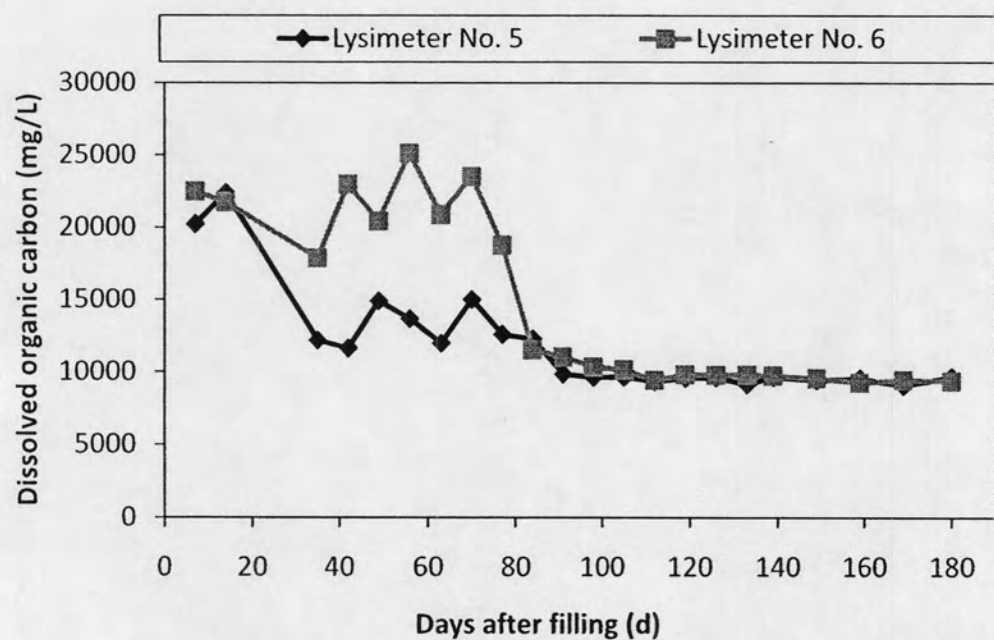


(e) Volatile acid

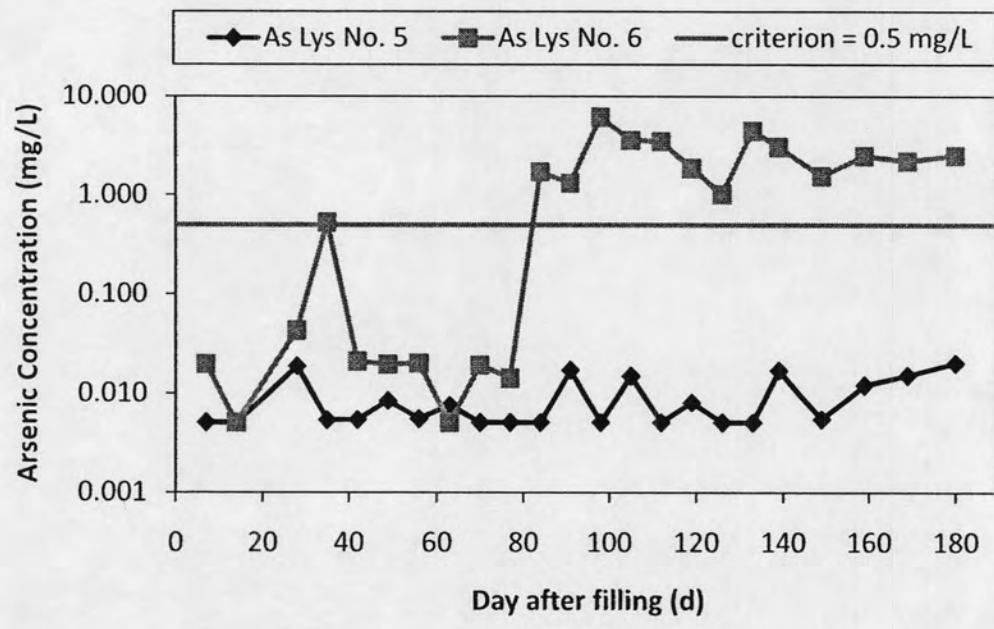


(f) Total organic carbon

Figure 4.10 Leachate characteristic variations over time from Lysimeter Nos. 5 and 6
(continued)

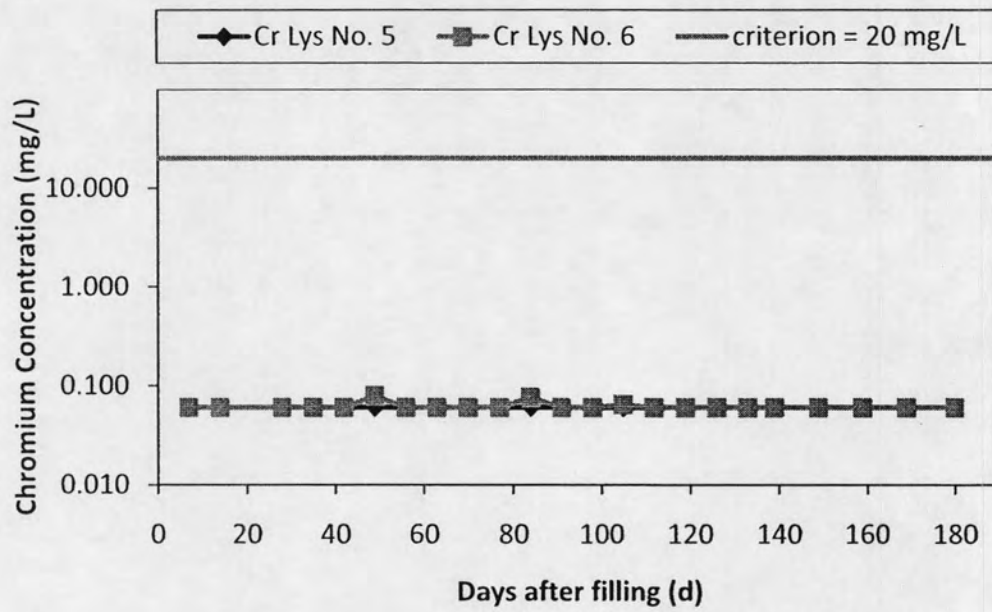


(g) Dissolved organic carbon

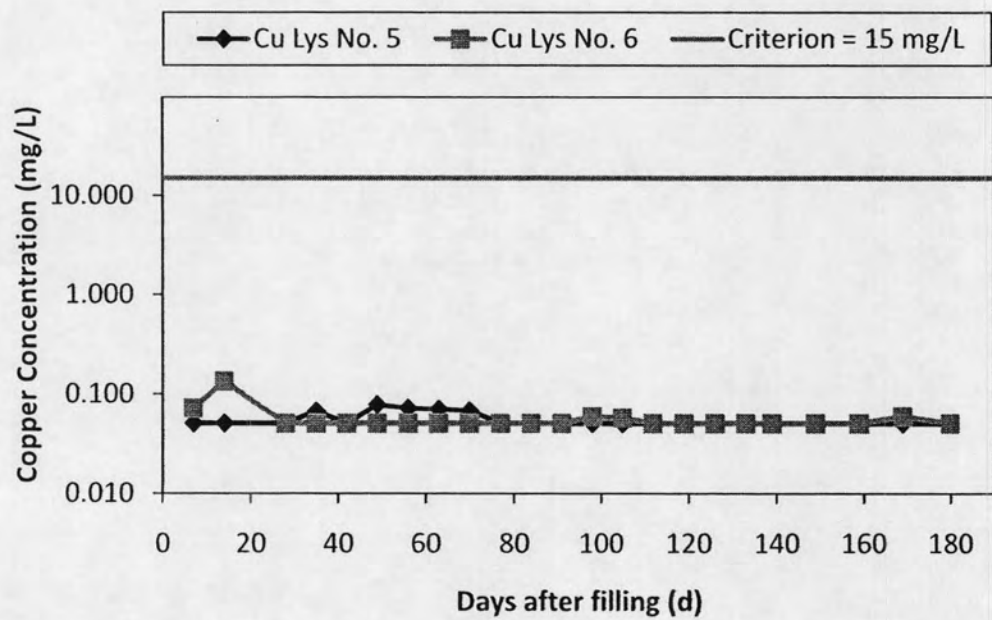


(h) Arsenic

Figure 4.10 Leachate characteristic variations over time from Lysimeter Nos. 5 and 6 (continued)



(i) Chromium



(j) Copper

Figure 4.10 Leachate characteristic variations over time from Lysimeter Nos.5 and 6
(continued)

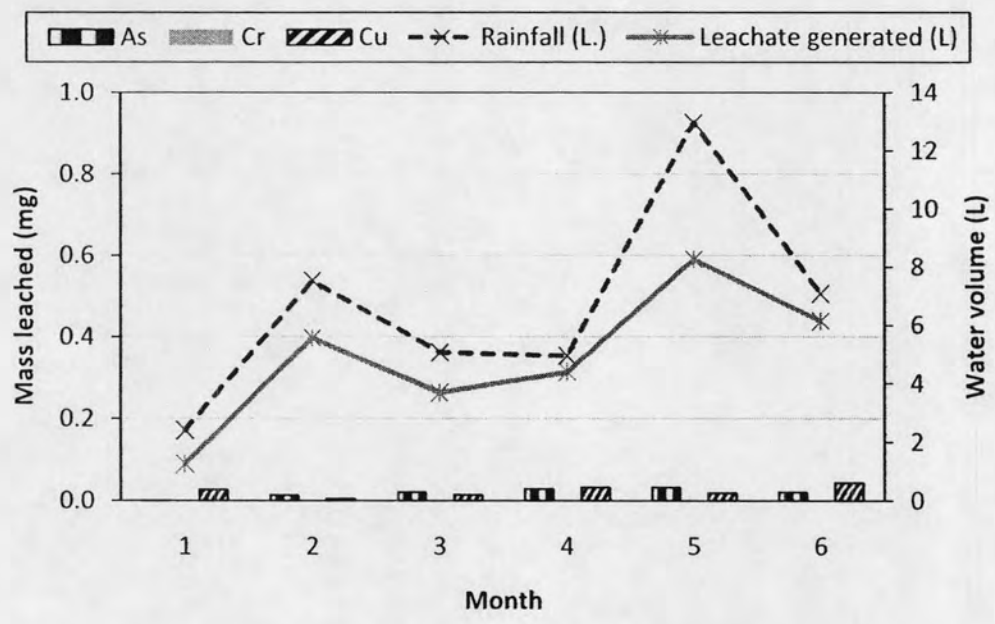
4.2.4 Metal mass leached out

4.2.4.1 Monthly metal mass leached out

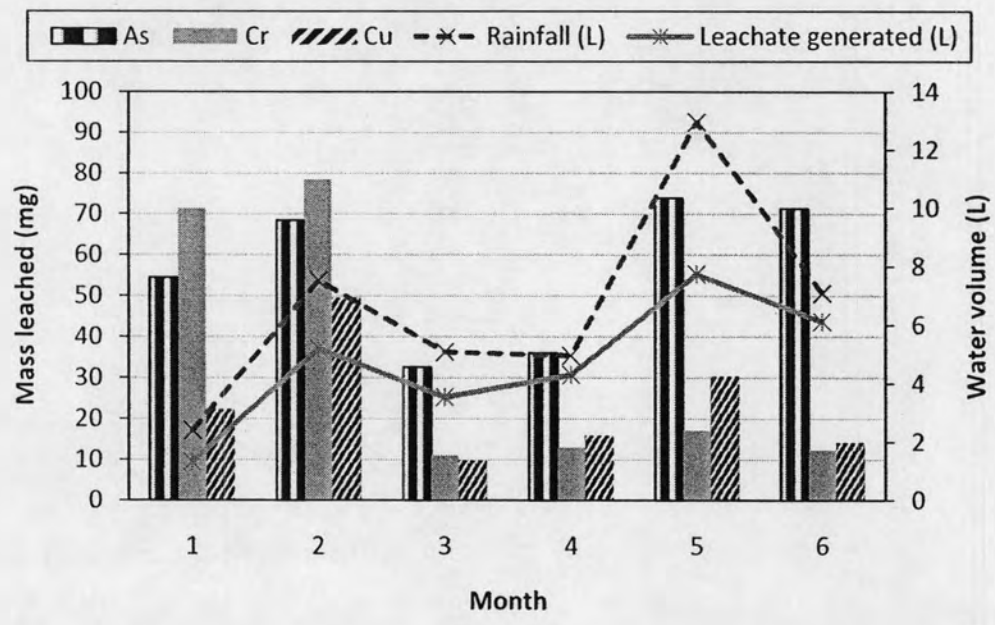
The monthly metal mass, which leached out, along with the monthly simulated rainfall amount that was added and the leachate amounts from each lysimeter are shown in Figure 4.11.

In the monofill lysimeters, low amounts of all metals were leached from Lysimeter No. 1 while very high amounts of all metals were observed in Lysimeter No. 2. In general, the amounts of the three metals leached out from Lysimeter No. 2 varied according to the amounts of the simulated rainfall that were added and the leachate generated, especially for arsenic. However, it was observed that very high amounts of all three metals leached out in the first month even though the amount of simulated rainfall that was added was low, as compared with the later months. This might have occurred because of the leaching out of the metals from the CCA solution residue on the treated wood surface during the beginning period.

For the C&D debris lysimeter (Lysimeter Nos. 3 and 4), all of the metals that leached out from Lysimeter No. 3 were found to be very low, as compared with those of Lysimeter No. 4. However, the variation patterns were not the same as those found in the monofill lysimeters. During the first few months after the filling of waste, the leachate amounts generated from the C&D debris lysimeters was smaller than those observed in the monofill lysimeters due to the high moisture capacity of the gypsum drywall in Lysimeter Nos. 3 and 4. When the holding capacity of moisture in the waste was reached, the leachate amount became high from the beginning of the fourth month until the end of the experiment. In general, the amount of arsenic varied according to the amounts of simulated rainfall that was added and leachate generated, except for during the last month when the arsenic concentration was found to be very high, as compared with that of the former period. The increasing rate of wood biodegradation in the later period might have occurred and resulted in the leaching out of a higher amount of arsenic from the inner layer of the wood.

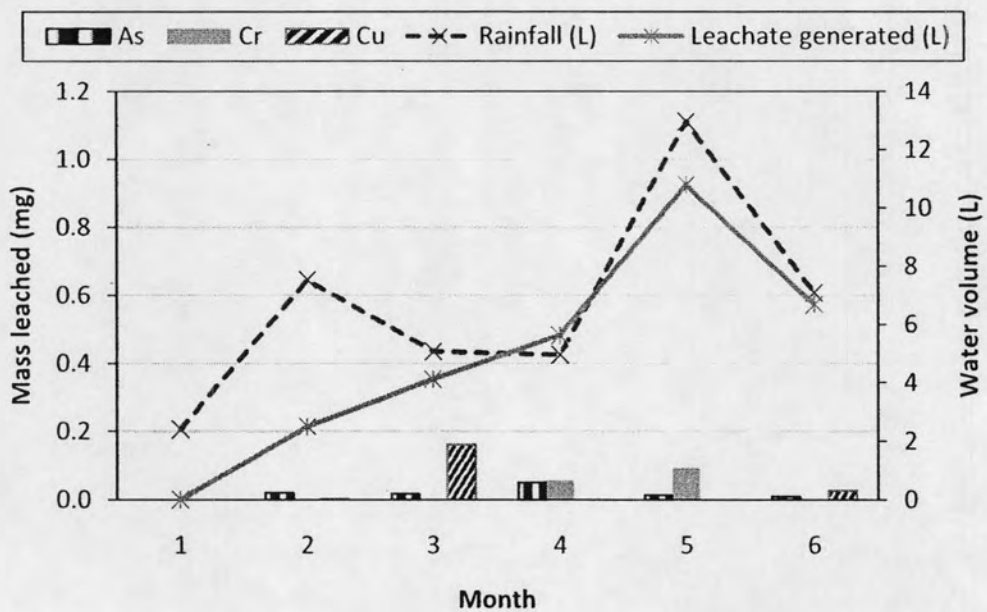


(a) Lysimeter No. 1

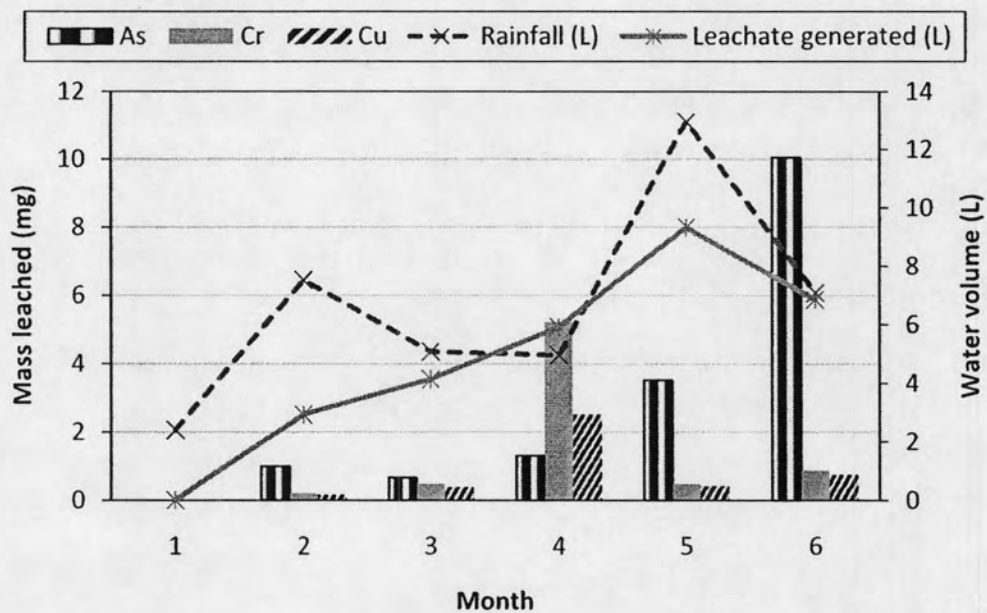


(b) Lysimeter No. 2

Figure 4.11 Monthly mass values of leached arsenic, chromium, and copper



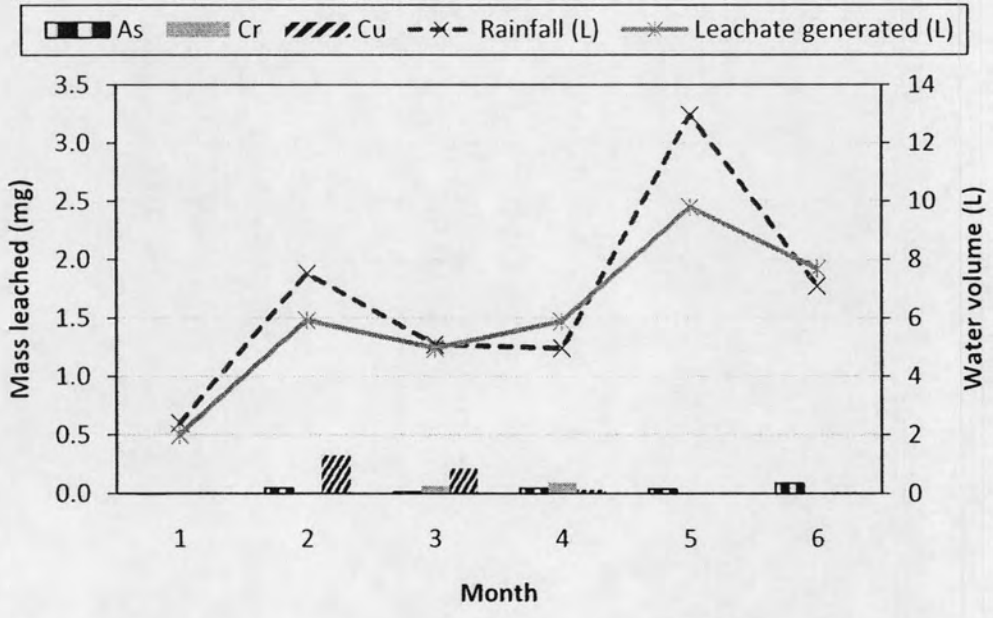
(c) Lysimeter No. 3



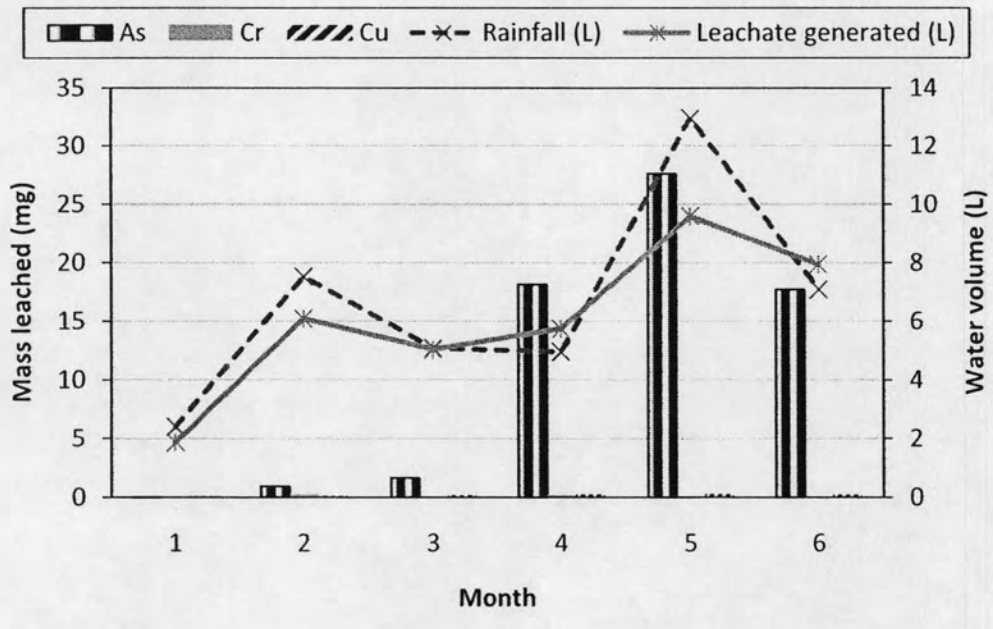
(d) Lysimeter No. 4

Figure 4.11 Monthly mass values of leached arsenic, chromium, and copper

(continued)



(e) Lysimeter No. 5



(f) Lysimeter No. 6

Figure 4.11 Monthly mass values of leached arsenic, chromium, and copper

(continued)

As was found in the monofill and C&D debris lysimeters, higher amounts of metal leached out from the MSW lysimeter filled with CCA-treated wood, as compared with the MSW lysimeter with non-CCA-treated wood. Taking into consideration the leaching out of arsenic in Lysimeter No. 6, it was observed that low amounts of metal were leached out during the first three months when the pH was low, as compared with the later period. This might be because of the precipitation of arsenic as arsenic sulfides (As_2S_3 or AsS) under acidic conditions (Moore et al., 1998). In addition, the organic contents in the waste layer and leachate during the initial period might have constituted the molecular weight distributions and metal complexation that differed from those found in the latter period (He et al., 2006). Moreover, the amounts of chromium and copper were found to have leached out in smaller proportions to that of arsenic, as compared to the monofill and C&D debris lysimeters. It seems that a higher complexation process of chromium and copper in the waste layer had occurred, as compared with the arsenic.

4.2.4.2 Total metal mass of pollution

The total metal mass leached out per kilogram unit of waste (wet weight) from each lysimeter was also determined to obtain a clear understanding of the leaching process. Table 4.4 summarizes the arsenic, chromium, and copper results for each scenario's lysimeter.

All three control lysimeters (Lysimeter Nos. 1, 3, and 5) were found to be in the range of 0.0043-0.0080 mg/kg for arsenic, 0.0000-0.0058 mg/kg for chromium, and 0.0055-0.0216 mg/kg for copper. For the experimental lysimeters (i.e., Lysimeters Nos. 2, 4, and 6), the highest concentration of all three metals was observed in the wood monofill scenario, while the lowest concentration was observed in the MSW scenario (except for arsenic, where the lowest concentration was observed in the C&D debris scenario).

The wood monofill with CCA-treated wood lysimeter leached the highest mass of arsenic (14.29 mg/kg), followed by chromium (8.635 mg/kg) and copper (6.048 mg/kg), respectively. For the C&D debris lysimeter with CCA-treated wood, the metal mass of arsenic was highest (0.6048 mg/kg), followed by chromium (0.2650 mg/kg) and copper (0.1686 mg/kg), respectively. The MSW lysimeter with

CCA-treated wood leached out more arsenic (2.268 mg/kg) than copper and chromium (0.0428 and 0.0237 mg/kg, respectively).

Table 4.5 shows % fraction of the metals that leached from the wood samples that were in each lysimeter. In the wood monofill lysimeter which was filled with 100% of CCA-treated wood (Lysimeter No. 2), arsenic leached from the wood sample at the highest percentages (2.796%); it was followed by copper and chromium (1.348% and 1.070%), respectively. The same trend was observed, % fraction of the metals in C&D debris lysimeter which was filled with 7% of CCA-treated wood (Lysimeter No. 4) and MSW lysimeter which was filled with 2% of CCA-treated wood (Lysimeter No. 6). The % fraction of leached arsenic, chromium, and copper were found to be 1.689%, 0.4684%, and 0.5343% from Lysimeter No. 4 and 22.54%, 0.1489%, and 0.4848% from Lysimeter No. 6, respectively. It was observed that a high percentage of arsenic leached from Lysimeter No. 6. It might be because the waste components were nearly saturated the duration of the experiment therefore the biological process might enhance arsenic leaching to the environment. It should be noted that arsenic leaches from CCA-treated wood primarily as either As(V) or As(III). As(III) is more mobile in the environment than As(V). On the other hand, chromium predominantly leaches as Cr(III), which has lower solubility in water than Cr(VI) (Solo-Gabriele et al., 2004). Therefore, a low fraction of chromium was observed.

Table 4.4 Summary of each metal's mass from each lysimeter

Metal mass leach (mg/kg)	Wood monofill lysimeters		C&D debris lysimeters		MSW lysimeters	
	Lys No. 1	Lys No. 2	Lys No. 3	Lys No. 4	Lys No. 5	Lys No. 6
Arsenic	0.0046	14.29	0.0043	0.6048	0.0080	2.268
Chromium	Nil	8.635	0.0058	0.2650	0.0060	0.0237
Copper	0.0055	6.048	0.0074	0.1686	0.0216	0.0428

Table 4.5 Fraction of arsenic, chromium, and copper leached from the wood samples added into each lysimeter

	Wood monofill		C&D debris		MSW	
	lysimeters		lysimeters		lysimeters	
	Lys No. 1	Lys No. 2	Lys No. 3	Lys No. 4	Lys No. 5	Lys No. 6
Arsenic	Nil	2.776	Nil	1.689	Nil	22.54
Chromium	Nil	1.062	Nil	0.4684	Nil	0.1489
Copper	0.3816	1.348	3.650	0.5343	42.80	0.4848

4.2.5 Evaluation of the potential impact of CCA-treated wood disposal on groundwater quality

The range and average leachate characteristics from Lysimeter Nos. 1–6 are summarized in Table 4.6.

The average concentrations of heavy metals analyzed in this study were compared to the criteria which amounts equal to 10 times the regulated limits listed in the Groundwater Standards for Drinking Purposes in Thailand from the Notification of the Ministry of Industry (standards of arsenic, chromium, and copper concentrations in the groundwater for drinking purposes are 0.05, 2.0, and 1.5 mg/L, respectively). It was discovered that the average amounts of arsenic in all three experimental lysimeters were found to be above the criteria (0.5 mg/L). The average amounts of chromium and copper leached from the experimental lysimeters did not exceed the criteria (which are 20 mg/L for chromium and 15 mg/L for copper). It might be concluded from this study that the disposal of CCA-treated wood in a wood monofill, the co-disposal of CCA-treated wood with C&D debris, and the co-disposal of CAA-treated wood with municipal solid waste could potentially result in groundwater contamination by arsenic.

Table 4.6 Ranges and averages of the leachate characteristics from Lysimeter Nos. 1 - 6

Parameter	Unit	Lysimeter No.												criteria
		1		2		3		4		5		6		
		Range	Avg. ±SEM	Range	Avg. ±SEM	Range	Avg. ±SEM	Range	Avg. ±SEM	Range	Avg. ±SEM	Range	Avg. ±SEM	
pH		5.17- 7.56	6.50 ±0.0908	5.94- 7.08	6.53 ±0.0524	6.17- 7.72	7.35 ±0.0590	6.83- 8.02	7.61 ±0.0632	3.74- 6.77	5.48 ±0.1396	3.86- 5.82	5.33 ±0.1105	
Cond.	ms/cm	0.16- 0.78	0.36 ±0.0324	0.42- 0.77	0.58 ±0.0182	1.98- 3.63	3.11 ±1.080	1.50- 3.55	3.06 ±0.1229	10.2- 24.1	16.6 ±0.7150	11.7- 23.4	17.87 ±0.7912	
ORP	mV	56-263	162 ±10.99	25-283	234 ±5.701	136-234	186 ±5.425	125-219	173 ±4.622	7.45- 139	58.6 ±8.756	7.44- 128	53.15 ±8.110	
TOC	mg/l	33-241	125 ±14.10	14-142	83.0 ±8.632	63-141	88.0 ±4.656	33-110	76.0 ±4.708	9382- 24721	12903 ±1019	9382- 28548	15916 ±1424	
DOC	mg/l	33-241	115 ±14.27	13-140	75.1 ±8.004	58-137	84 ±4.778	32-99	74.0 ±4.390	9250- 22382	11860 ±764.9	9250- 25134	14700 ±1285	
TA	mg/l									3490- 12300	7420 ±464.3	5980- 12960	8450 ±491.8	

Table 4.6 Ranges and averages of the leachate characteristics from Lysimeter Nos. 1 - 6 (continued)

Parameter	Unit	Lysimeter No.												criteria
		1		2		3		4		5		6		
		Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	
VA	mg/l									2830- 47200	12340 ±2636	2350- 43400	13800 ±2770	
As	mg/l	<0.005- 0.02	<0.005	<0.005- 88.6	15.7 ±4.573	<0.005- 0.02	0.01 ±0.0012	<0.05- 2.58	0.53 ±0.1419	<0.005- 0.02	0.01 ±0.0014	<0.005- 6.16	1.57 ±0.3576	0.5
Cr	mg/l	<0.06	<0.06	<0.06- 134	13.6 ±6.428	<0.06	<0.06	<0.06- 2.02	0.26 ±0.1054	<0.06- 0.08	<0.06	<0.06- 0.08	<0.06	20
Cu	mg/l	<0.05	<0.05	<0.05- 48.4	6.32 ±2.402	<0.05- 1.13	<0.05	<0.05- 0.89	0.16 ±0.054	<0.05- 0.08	<0.05	<0.05- 0.13	<0.05	15

Criteria: Ten times the limited amount regulated in Groundwater Standards for Drinking Purposes in Thailand from the Notification of the Ministry of Industrial (MOI, 1997)

4.2.6 Comparison between the batch leaching test and column test

Toxicity characteristic leaching procedure (TCLP) and waste extraction test (WET) are batch tests that are used to estimate the leaching potential of waste when waste is disposed in a land. The acids used in TCLP and WET are acetic acid and citric acid, respectively. The liquid to solid ratio for the extraction (LS) used in TCLP and WET are 20 and 10, respectively. Lysimeter test (column test) involve adding a leaching solution (distilled water was used in this study) to the top of a depth of waste, letting the leaching solution flow through the waste (under gravity), and collecting and measuring the leachate coming out from the bottom. The liquid to solid ratio for the monofill lysimeter test (Lysimeter No. 2) at the end of the experiment (six-month experimental) was 1.12. In this study, the batch leaching test results were compared to the monofill lysimeter test results. In the lysimeter study, the new hardwood was filled as a wood sample. Therefore, the results of the batch leaching tests of the new hardwood (cross-section, see Table 4.1) using batch leaching tests were only considered for the comparison.

Table 4.7 presents the LS, the average pH, metal concentrations, total percentage of each metal released, ratios of arsenic to copper (As/Cu), and copper to chromium (Cu/Cr) and Figure 4.12 shows the variation of cumulative percentages of the three metals leached from Lysimeter No. 2 over the LS ratio.

The final pH values of batch leaching tests were lower than the average pH of the lysimeter test. The metal concentrations in the batch leaching tests were lower than the lysimeter test (except for copper) due to the higher lower amount of samples used in the batch test, compared with the lysimeter test. However, the higher percentage of all metals leached were observed in the batch leaching tests due to the lower pH value and the higher LS ratio in the batch tests, compared with the lysimeter test. The higher % fraction of metals in the WET test was observed, compared with the TCLP test due to the lower LS and different acid used in the WET test, compared with the TCLP test. As presented in Table 4.7, the ratio of As/Cr and Cu/Cr in batch leaching tests were 8.07 and 3.88 for the TCLP test and 2.04 and 2.34 for the WET test, respectively. These ratios were different from the lysimeter test

which were 1.15 and 0.46 for As/Cr ratio, respectively. Considering to the ratios of the three metals mentioned above, the results clearly showed that in the lysimeter test, the fraction of arsenic leached was higher than copper and chromium, compared with the batch tests. This indicated that copper and chromium leaching might be inhibited in the lysimeter environment. In addition, the cumulative percentages of the three metals at different LS ratio presented in Figure 4.1 showed that the % fraction of copper and chromium in the lysimeter test was also inhibited when LS ratio increased. These varying ratios are a reflection of the fact that the environment in the lysimeter is different than the environment of the batch leaching tests. The results obtained from this study were also corresponding to the study of Jamback (2006).

Table 4.7 Metal concentrations in the leachate from the lysimeter and batch leaching tests

	Column test ^a	Batch leaching tests	
	Lys No. 2	TCLP	WET
LS at end of test/experiment	1.12	20	10
Leachate pH	6.53 ^b	4.76 ^c	4.93 ^c
Arsenic (mg/L)(% fraction)	15.7 (2.96%)	9.21 (8.94%)	9.19 (71.4%)
Chromium (mg/L)(% fraction)	13.6 (1.24%)	1.14 (0.7%)	4.50 (22.1%)
Copper (mg/L)(% fraction)	6.32 (1.24%)	4.83 (5.34%)	10.55 (33.45)
Arsenic/chromium ratio	1.15	8.07	2.04
Copper/chromium ratio	0.46	3.88	2.34

^a Average metal concentrations leached over 180-day experiment

^b Average pH from all values measured during the experiment

^c Final pH of leachate after batch leaching tests completed (average of three samples)

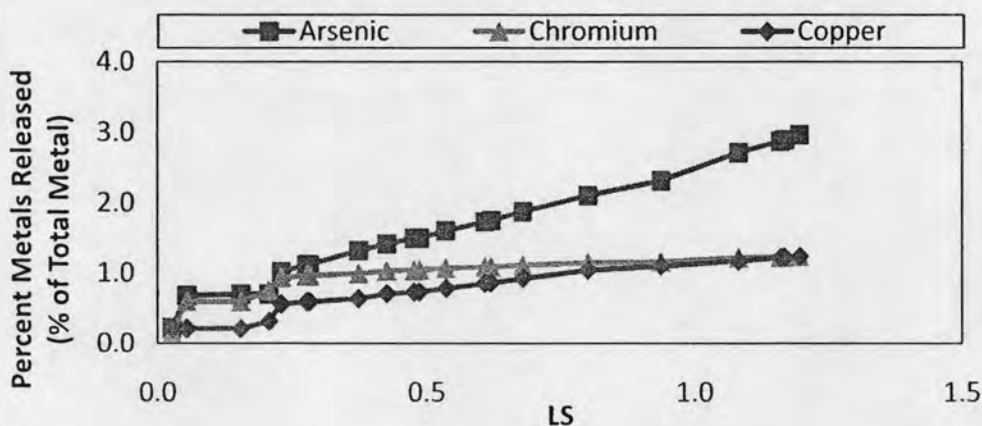


Figure 4.12 Cumulative percentage of arsenic, chromium, and copper leached from Lysimeter No. 2 at different LS ratio