

## **Battery Corrosion and Mercury migration in Landfill**

(Fifteen Years of Experiment using Landfill Containers)

### 1. Summary

This study was carried out to examine the corrosion conditions and mercury transfer status of EOL dry batteries containing mercury by

use of small experimental containers to create a condition as similar as landfill. The batteries were put into the simulated-landfill containers and the containers were regularly disassembled one after another for observing the status change in a time period of 15 years.

It is found that for the first two years the corrosion of dry batteries subject to the landfill experiment were greatly influenced by the quality of exudate, which changed according to the landfill structure, and the voltage retained in the batteries. After the remaining voltage had been consumed, the corrosion progressed faster when the time period of landfill became longer. Mercury contained in batteries did not flow out into exudate, but came out as evaporated mercury and transferred into waste layers. It is recognized, however, that the concentration of mercury was high in the middle layer where the batteries were set in the containers and the mercury had a tendency to difficultly move into lower and higher layers even after 15 years of landfill.

### 2. Conclusion

In this study, the dry battery corrosion and mercury transfer were examined from the water quality of exudate in the containers with passage of time and by regular disassembly of the containers (after 0.5, 1, 2, 7 and 15 years of landfill). The results obtained from the study are as follows:

- (1) In the beginning period of landfill, the Hg concentration in exudate was 0.0004 mg/l. to 0.001 mg/l. in the group of quasi-aerobic landfill experimental containers. This value exceeds the environmental standard value but remains below the wastewater quality standard value. In the group of anaerobic containers, the Hg

concentration was 0.0002 mg/l. to 0.0004 mg/l. This indicates that the mercury flowing-out rate from battery to exudate was below 1.5% for each landfill period. In other words, there was very little mercury that flowed out into landfill and mercury was kept contained in batteries.

- (2) Considering the status change of dry battery corrosion from the beginning of the experiment to the end of its 15<sup>th</sup> year, we found the features of the corrosion that are summarized as follows: (1) In the beginning period of landfill, the difference of landfill structure caused the change in the water quality of exudate; (2) corrosion speed was high in the first two years during which the retaining voltage were being consumed, but after the completion of the consumption the speed became lower; (3) corrosion progressed faster when the time period of landfill became longer.
- (3) Mercury flowed out from corroded dry batteries as evaporated mercury. The concentration of the mercury had a tendency to increase when the landfill period became longer.
- (4) Concerning the concentration of mercury in the containers according to their layers after 15-year landfill, it is confirmed by the disassembly of the containers that the concentration in the middle layer (lower portion of the middle layer, in particular) was higher and that mercury certainly transferred from dry batteries to waste layers. At the same time, this suggests that the most part of mercury remained in the middle layer and mercury transferred difficultly to the upper and lower layers.
- (5) Concerning mercury flowing out from dry batteries into waste layers as evaporated mercury, it is assumed that, when landfill period becomes long, the mercury possibly flows out from waste in case of aerobic containers but it difficultly flows out in case of anaerobic containers.

It is therefore concluded from the study that mercury contained in batteries was influenced by the landfill structure, landfill period and battery voltage and flowed out from corroded

batteries as evaporated mercury.

However, it shall be noted that the mercury that had flowed out tended to remain in waste layer and difficult to move out.

Table 1 Experimental condition

Name of lysimeter	LS-1	LS-2	LS-3	LS-4	LS-5	LS-6	LA-1	LA-2	LA-3	LA-4	LA-5	LA-6
Experimental period (years)	15 (control)	15	7	2	1	0.5	15 (control)	15	7	2	1	0.5
Kind of filling material	incineration residues 38%, glass (crushed stone) 20% metals (empty cans and sheet) 10%, plastics 2% sewage sludge 15%, sludge (compost) 10%, woods 5%											
Landfill type	Semi-aerobic						Anaerobic					
Weight of filling material (kg)	70	69	69	69	69	69	69	69	69	69	69	69
Number of dry batteries	0	24	24	24	24	24	0	24	24	24	24	24

Table 2 Filling condition of dry batteries

Kind of dry batteries	SUM1, SUM3, MR52, LR20, LR6, LR44
Physical condition	electric charged or electric discharged pressed or not pressed
Filling number	24 pieces per lysimeter

Table 3 Total content of Hg in lysimeter

Kind of filling solid waste	Weight (dry-kg)	Hg (mg/kg)	Hg (mg)
incineration residue	18.8	0.208	3.91
woods	2.0	0.003	0.01
sewage sludge	6.9	0.863	5.95
sludge (compost)	2.8	1.065	2.98
metals (empty cans)	2.7	0.25	0.68
plastics	1.4	N.D	0
glass (crushed stones)	13.8	0.004	0.06
Total	48.4		13.59

Table 4 Leaching rate of heavy metals into leachate

Lysimeter	Hg (%)	Zn (%)	Lysimeter	Hg (%)	Zn (%)
LS-1	1.25 (0.29)	0.26	LA-1	1.17 (0.09)	0.48
LS-2	1.33 (0.16)	0.27	LA-2	0.96 (0.14)	0.77
LS-3	0.66 (0.11)	0.22	LA-3	0.58 (0.16)	0.35
LS-4	0.27 (0.11)	0.18	LA-4	0.18 (0.03)	0.11
LS-5	0.19 (0.06)	0.17	LA-5	0.11 (0.009)	0.44
LS-6	0.07 (0.06)	0.10	LA-6	0.03 (0.004)	0.08

Each leaching amount during the experimental period per the initial content without battery (LS-1, LS-2, LA-1, LA-2: 15years, LS-3, LA-3: 7years, LS-4, LA-4: 2year, LS-5, LA-5: 1year, LS-6, LA-6: half year)

Table 5 Corrosion rate and peel rate of dry batteries

period	voltage	corrosion area (%)		peel area (%)	
		semi-aerobic	anaerobic	semi-aerobic	anaerobic
0.5 year	charged	16.5	37.5	–	–
	discharged	7.5	8.2	–	–
1 year	charged	23.4	47.1	4.7	13.3
	discharged	7.6	8.4	0.8	0.6
2year	charged	24.5	25.8	4.0	1.8
	discharged	17.2	20.9	0.1	2.3
7year	charged	51.2	42.5	29.6	13.5
	discharged	20.5	21.2	4.2	3.2
15year	charged	84.0	77.0	21.2	27.1
	discharged	73.5	88.8	3.7	8.1

Table 6 Contribution of various factors to the corrosion rate of dry battery

Factor	SUM1				SUM3				LR20			
	1 year	2 years	7 years	15 years	1 year	2 years	7 years	15 years	1 year	2 years	7 years	15 years
Landfill type A	***12.1	*** 9.2	* 4.0	(*) 1.1	*** 26.5	*** 17.9	** 7.3	* 5.3	*** 15.6	*** 14.1	*** 6.6	* 1.9
Battery voltage B	***40.5	*** 34.4	*** 36.8	* 9.0	*** 51.5	*** 18.6	*** 19.7	* 3.8	***46.4	*** 47.9	*** 49.3	*** 9.8
Deformation C	—	—	—	—	—	* 2.5	—	(*) 0.1	** 5.6	—	—	—
Landfilling period D	*** 6.8	** 9.5	*** 22.9	***59.1	* 2.3	** 13.5	***24.4	*** 69.4	** 5.9	* 3.6	*** 9.3	*** 73.4
A×B	***18.0	***12.0	** 5.1	—	*** 8.6	—	—	—	* 5.3	—	—	(*) 0.1
A×C	—	* 2.4	—	—	* 1.6	—	(*) 0.8	(*) 1.3	—	—	—	—
A×D	*** 6.9	** 6.2	—	—	—	—	—	(*) 2.4	—	* 6.1	** 7.4	(*) 2.1
B×C	—	—	—	(*) 0.6	—	—	—	(*) 0.2	—	* 3.4	(*) 1.7	—
B×D	*** 7.8	** 8.7	* 7.2	(*) 3.8	* 2.1	***21.0	** 12.1	(*) 3.0	** 6.3	(*) 2.5	—	* 3.5
C×D	—	—	—	—	—	* 4.7	* 6.4	(*) 3.1	* 4.6	—	—	(*) 1.1
A×B×C	—	—	—	—	* 1.7	—	—	—	—	* 2.4	—	(*) 0.2
A×B×D	*** 5.1	** 6.4	(*) 2.7	(*) 2.1	—	* 4.8	—	—	—	** 8.4	(*) 9.8	* 3.2
A×C×D	—	—	—	—	—	* 3.5	—	(*) 1.1	—	—	—	(*) 0.1
B×C×D	—	—	—	—	—	* 4.0	(*) 2.7	(*) 0.5	* 3.0	—	—	(*) 1.0

Factor	LR6				LR44				MR52			
	1 year	2 years	7 years	15 years	1 year	2 years	7 years	15 years	1 year	2 years	7 years	15 years
Landfill type A	—	—	(*) 0.1	—	(*) 4.3	—	—	—	***21.7	*** 15.2	(*) 2.5	(*) 0.1
Battery voltage B	***80.8	***48.2	***41.4	**13.5	***29.2	***32.3	***30.7	* 3.6	***37.0	*** 26.0	***24.2	(*) 4.5
Deformation C	—	* 5.3	* 4.9	(*) 0.1	(*) 4.4	—	(*) 1.6	—	* 3.1	* 3.0	—	—
Landfilling period D	(*) 2.4	—	(*) 7.6	***58.8	—	—	* 7.8	*** 79.2	—	—	(*) 5.1	*** 63.5
A×B	—	—	—	(*) 0.5	*** 24.7	** 13.1	*** 18.2	—	*** 16.7	*** 13.6	(*) 2.1	—
A×C	—	—	—	—	* 9.8	(*) 3.9	—	—	** 6.3	** 4.4	(*) 2.0	—
A×D	—	—	—	(*) 0.9	—	—	—	(*) 3.5	—	** 5.0	(*) 5.1	—
B×C	—	—	(*) 0.4	(*) 0.6	* 7.7	—	—	—	* 3.8	** 6.3	—	—
B×D	(*) 2.8	***21.3	* 10.2	(*) 4.7	—	—	—	—	—	** 9.1	(*) 1.6	(*) 2.3
C×D	—	—	—	(*) 1.3	—	—	—	—	—	—	(*) 3.7	—
A×B×C	—	* 3.3	—	—	—	—	—	—	* 4.6	*** 6.8	—	—
A×B×D	—	—	(*) 4.1	(*) 1.0	—	* 6.3	(*) 4.9	* 4.9	—	* 2.7	(*) 3.0	—
A×C×D	* 2.9	—	—	—	—	(*) 4.3	—	(*) 0.8	—	(*) 1.6	—	—
B×C×D	—	—	—	—	—	* 11.9	* 7.2	(*) 0.2	—	—	(*) 7.0	—

\*\*\* calculated by 0.5% risk , \*\* calculated by 1.0% risk , \* calculated by 5.0% risk , (\*) calculated by 10.0% risk

Table 7 Concentration of mercury vaporized from corroded dry batteries

landfill type experimental period dry battery voltage	Semi-aerobic						Anaerobic					
	2 years		7 years		15 years		2 years		7 years		15 years	
	A	B	A	B	A	B	A	B	A	B	A	B
Number of batteries (piece)	12											
Amount of Vaporized Hg (ng)	6	92	1988	50	98	151	37	48	98	15	176	250
Abrasion rate in area	4	0.1	30	4	21	4	2	2	14	3	27	8

A:electric charged , B:electric discharged

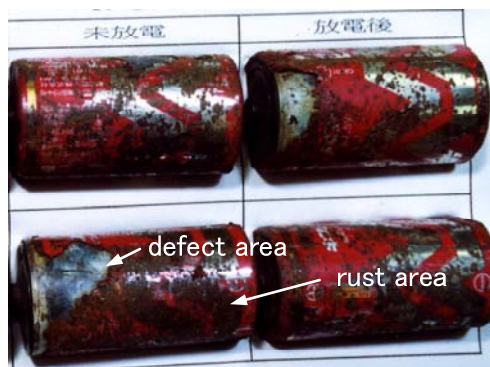


Photo 1 Corrosion of dry batteries (7 years after)

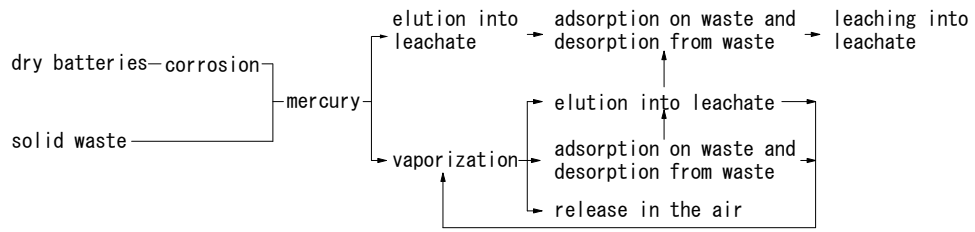


Fig.1 Effluence process of mercury from dry batteries and solid waste in landfill

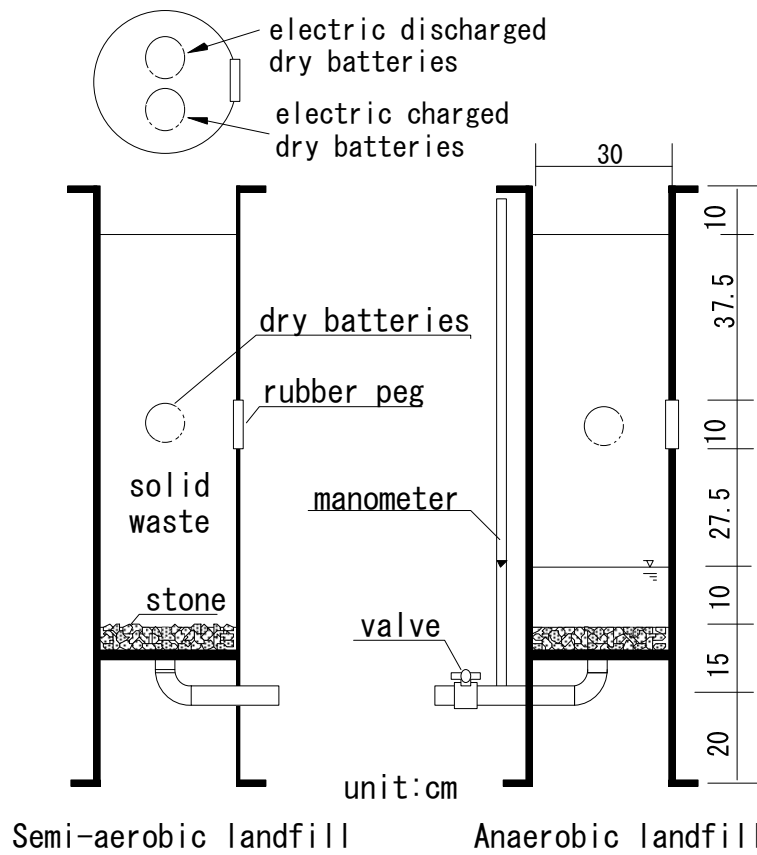


Fig.2 Experimental small-scaled lysimeter

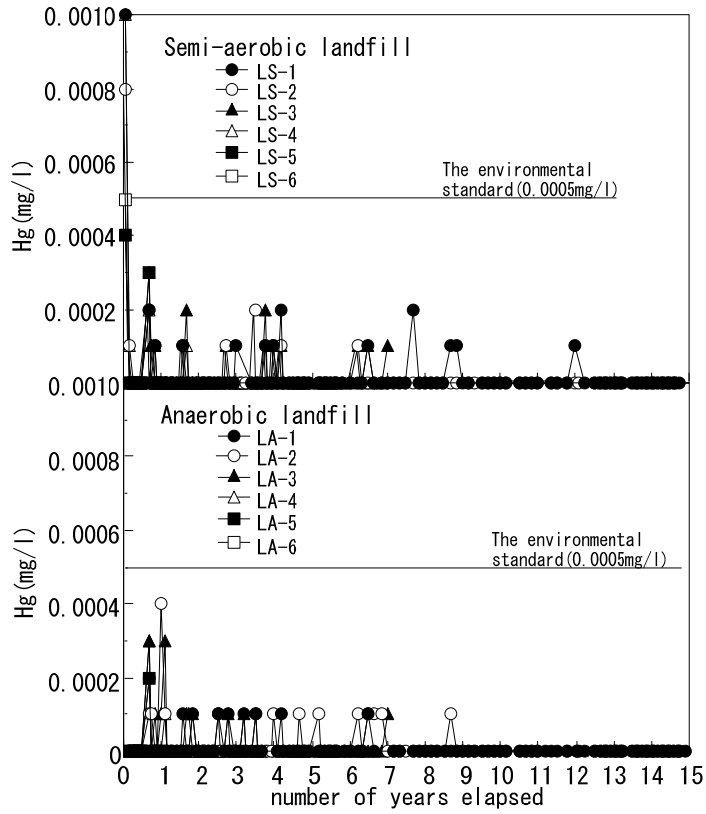


Fig. 3 Change in the concentration of Hg in leachate

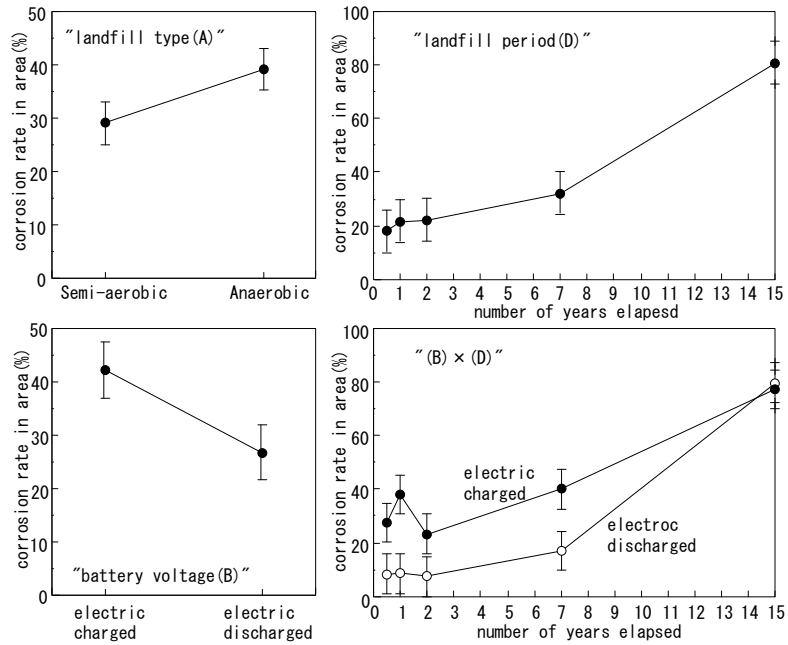


Fig. 4 Average corrosion rate in area by each factor (95% confidence limit)



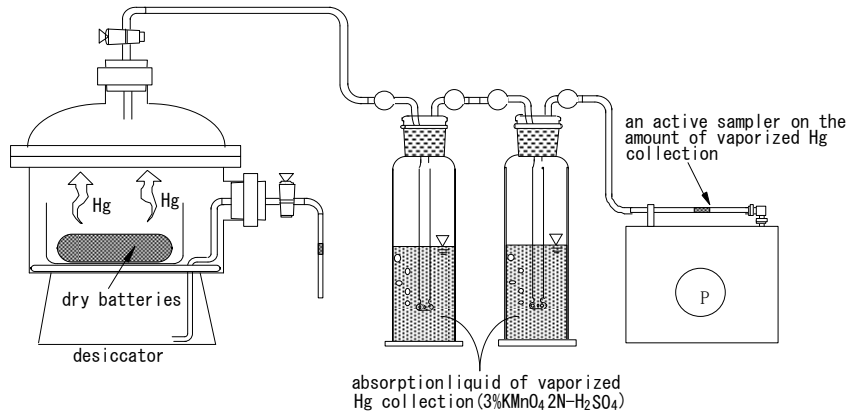


Fig. 5 An experiment of generation with vaporized mercury collection

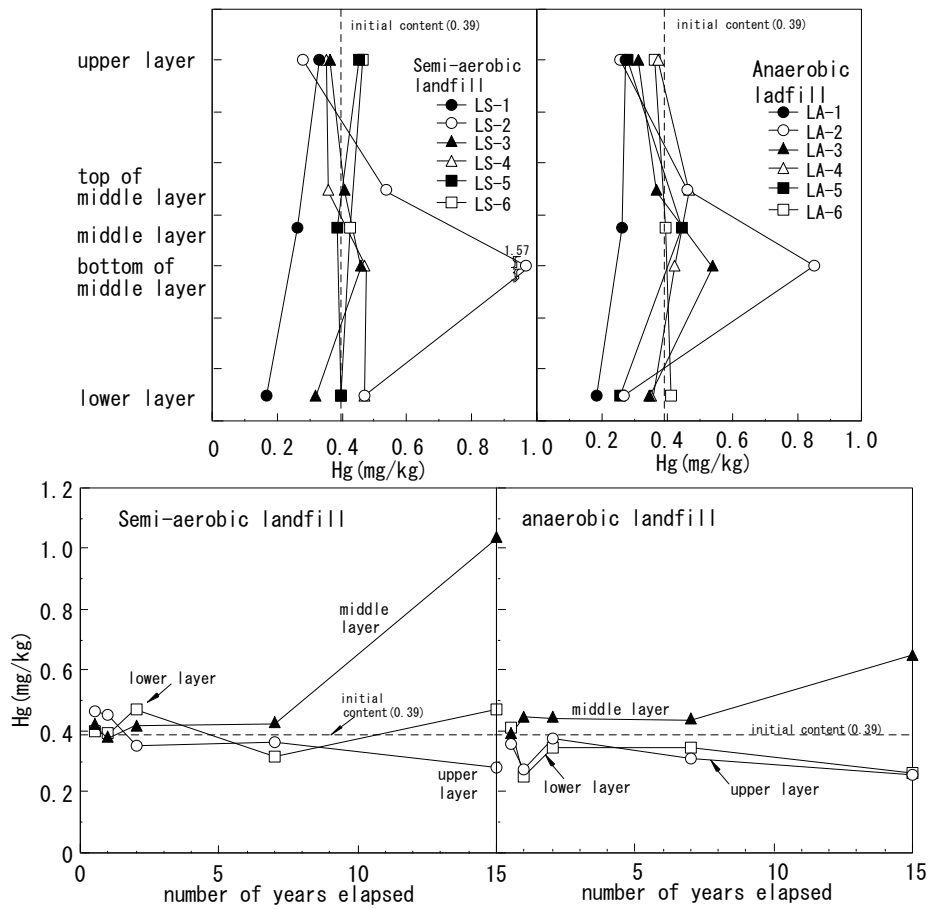


Fig. 6 Change in the distribution of Hg content by depth in lysimeter

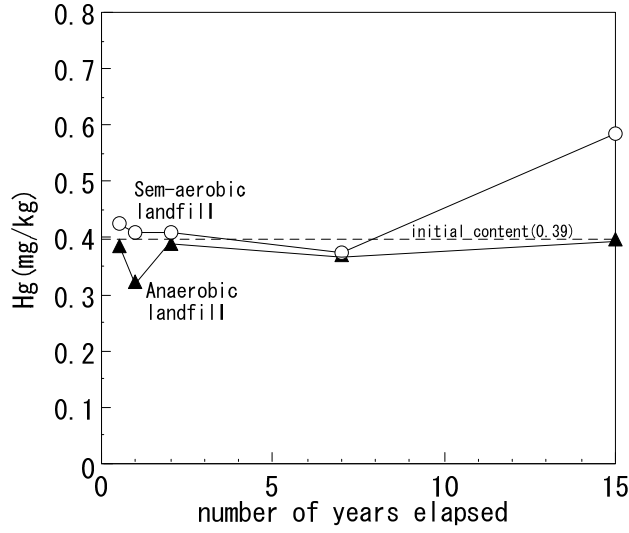


Fig. 7 Change in the Hg content by landfill type

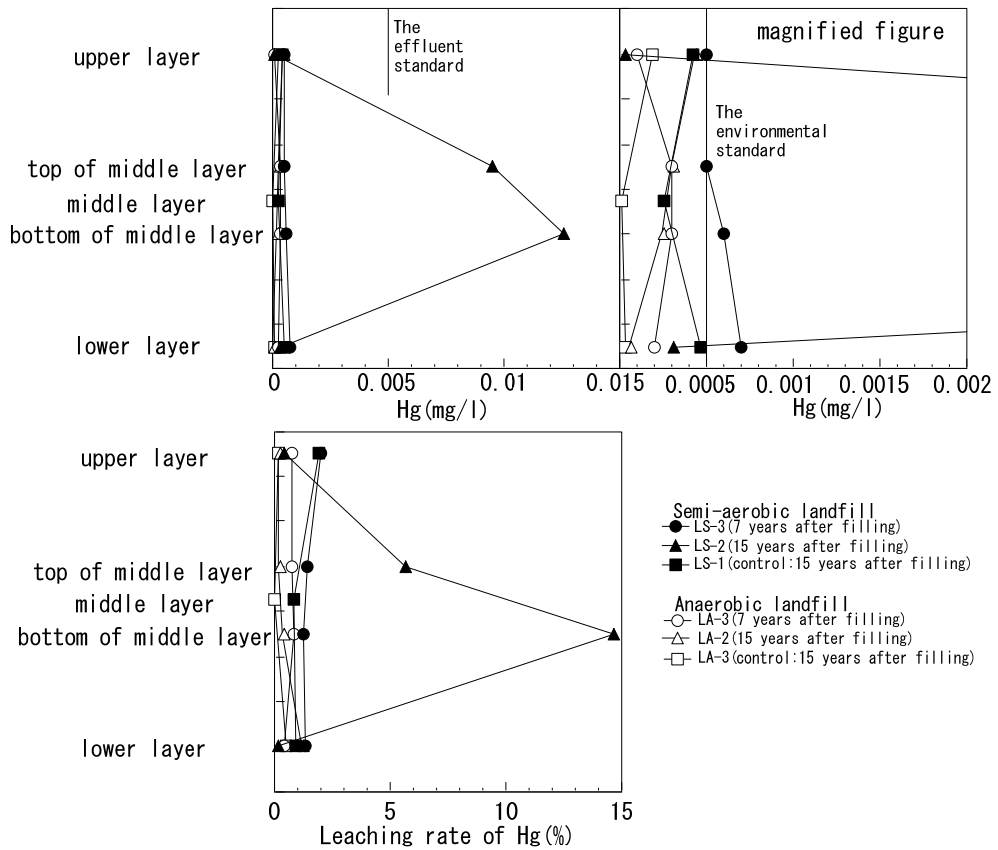


Fig. 8 Change in the concentration of Hg and leaching rate of Hg by elution test in solid waste (10mm under)