Study on the long-term carbon balance in an industrial solid waste landfill

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1. Introduction

Ideally, landfill aftercare should be terminated as soon as possible to minimize long-term environmental impact and maintenance costs. The carbon balance in a landfill can be used to estimate the degree of stabilization and aftercare period. Although many researchers have taken the carbon balance in landfills to estimate the time required for aftercare, most of them have had a timeline of only several months or years. In this study, a 20-year-old industrial waste landfill (S-Landfill) with five sites varying in age from 2 to 20 years was investigated. To estimate carbon balance in the landfill, waste characteristics were determined using previous study’s data, and a macro-moisture balance model of precipitation and infiltration was employed to estimate leachate generation.

2. Description of landfill

2.1 History

The S-Landfill is located in Hokkaido, Japan and composed of five sites. The first site began operations in 1985, and site 5 was opened in 2007. Each site has an area of approximately 20,000 m². Sites 3 and 4 have large amounts of deposited waste (175,445 and 249,854 tons, respectively) because these sites have greater heights than the others. Leachate amount and quality (BOD and COD) are monitored only at the leachate treatment facility, and these measurements have been recorded since 1999 and 1987, respectively.

2.2 Carbon input to landfill

Fig. 1 shows the categories of waste disposed of in the S-Landfill by time. Waste is classified into seven categories, of which sludge accounts for the largest percentage. To estimate carbon content of each category of solid waste, the proximate analysis (moisture, combustible, and ash content) and the ultimate analysis values (carbon, hydrogen, nitrogen, and oxygen) were determined using literature values. Based on the values, total carbon content in landfilled waste was calculated on a yearly basis as shown in Fig. 2. About 75% of total input carbon was derived from sludge. The highest value appeared in 2001 due to the sharp increase of wood waste disposal.

2.3 Leachate data

Leachate quality has been monitored for BOD₅ and COD₅₀ since 1987 and its monthly average values was shown in Fig. 2. Although, for some operational reasons, monitoring data were not recorded for 22 months from 1992-2003, yearly averaged BOD values could be used to estimate carbon release via leachate because seasonal variation is not significant. As mentioned above, leachate discharge has been measured since 1999 so the missing data were estimated using a macro-model.

![Fig. 1 Physical composition and estimated carbon weight of the landfilled waste](image_url)
3. Estimation of leachate generation

Infiltration rate is the most important factor in estimating leachate generation (Q). It is influenced by the existence of landfill cover: the infiltration rate is high when there is no cover and low when there is a cover. In this study, two categories of infiltration rates, \(K_o\) and \(K_c\), were assumed for an active site without a cover and a closed site with a cover.

\[
Q = I (K_o A_o + K_c A_c),
\]

where \(I\) is precipitation, and \(A_o\) and \(A_c\) are active and covered area in a landfill. Normally, \(K_o\) and \(K_c\) values are in the range of 0.5–0.7 and 0.1–0.4, respectively. In the S-Landfill, each site has 1 m of final cover and was vegetated after its closure, so \(K_c\) is set at the lowest possible value of 0.1, and \(K_o\) is set at an average value of 0.6. Leachate discharge is delayed due to dynamics in a landfill, so the amount of leachate discharge can be assumed using the following:

\[
Q_{d,im}^i = \alpha_2 Q_{im,2} + \alpha_1 Q_{im,1} + (1 - \alpha_2 - \alpha_1) Q_{im},
\]

where \(Q_{d,im}^i\) is leachate generation from site-\(m\) in \(i\)-th months, \(\alpha_1\) and \(\alpha_2\) are the ratio derived from \(i-1\) and \(i-2\) months before. Values for \(\alpha_1\) and \(\alpha_2\) were determined to be 0.5 and 0.2 by minimizing the error between calculated and observed leachate amounts since 1999. Fig. 3 shows the estimated leachate amount and yearly average BOD in mixed leachate.

4. Carbon balance

BOD data for leachate released from each site is required to estimate total carbon content in the leachate, but BOD values were only recorded for mixed leachate as shown in Fig. 3. BOD values are generally lower in older sites due to the advanced degradation and flushing effect of organic waste, so the following two approaches were used to estimate the range of carbon content released via leachate: 1) leachate from each site was assumed to have the observed BOD value, 2) the values for all closed sites were assumed to be zero. Carbon content in leachate was calculated from BOD values by assuming that carbon is converted to \(\text{CO}_2\). Regardless of landfill age, carbon mass released via leachate from each site ranged from 0.36–1.6% (less than 2% of total content).

5. Conclusions

In this study, the carbon content in dumped waste was estimated based on previously published data on organic content and carbon content. Leachate quantity data were missing for the first ten years and were therefore estimated using a macro-moisture balance model including the effect of snow melt. As a result, less than 2% of total input carbon was released from each site via leachate regardless of landfill age. To enable further accurate monitoring of the stabilization process via carbon balance, however, all data for landfilled waste and leachate need to be recorded precisely at each site.