A STUDY ON A WASTE STABILIZATION METHOD IN CLOSED SYSTEM DISPOSAL FACILITIES

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ABSTRACT

Recent studies on the waste stabilization in a landfill site have revealed the effectiveness of a washout gradually, which removes some kind of chemicals from waste. However, there is no concrete method for evaluating quantitatively the effectiveness of a washout. This study applies an optimal control theory and tried to evaluate a stabilization phenomenon of waste quantitatively. In the evaluation, the TOC concentrations in the leachate were calculated using a washout model in the process of the waste (bottom ash) stabilization a closed system disposal facility. Particularly, the effects of three operating variables in the watering for the washout, 1) intensity, 2) period, and 3) interval of watering, on the TOC concentration profiles were evaluated quantitatively. For the optimization of the sprinkling operation, a total cost in a leachate treatment until the TOC concentration reaches the acceptable level was used as an evaluation function. The optimization theory proposed in this study is a promising design method of watering and leachate treatment facilities for waste stabilization.

1 INTRODUCTION

Construction of landfills has recently become very difficult in Japan because of opposition from residents who feel uneasy about environmental pollution caused by the disposal of solid waste. In response to this difficulty, a new type of landfill site, called a "Closed System Disposal Facility" (CSDF), has been studied and put into practice in Japan. Because the CSDF can control emissions to the neighboring environment and the quality of landfill waste, the CSDF is acceptable to neighboring residents.

In this study, "waste stabilization control" is discussed since it is the most important function of the CSDF. Specifically, we investigated ideas and factors relating to waste stabilization and proposed an analytical method to promote waste stabilization.

Research to find a theoretical explanation of the elution behavior of toxic substances and other substances from waste or an effective method of eluting toxic substances and other substances from waste is still in its infancy. Moreover, attempts to control this elution behavior and evaluate quantitatively various elution methods are at an even more basic stage. The waste landfills in question are structures that are highly susceptible to rainfall and other natural phenomena (because waste landfill sites are located in the open air) and one of the challenges facing this research is the extensive level of disturbance encountered in attempting to control this elution behavior. To address this challenge, Hanashima and others have conceived a new type of disposal facility called a closed-system disposal facility (CSDF), which has recently spawned various R&D initiatives on a variety of topics. A CSDF is a disposal site covered by a roof to prevent rain from coming into direct contact with landfill waste. Many people are hopeful that CSDFs will facilitate control of the effects of the ambient environment on landfill waste and that CSDFs will also enable control of landfill waste itself. This has led to the development of multiple types of CSDFs. As of 2006, some 44 CSDFs have been constructed in Japan.

In this paper, we discuss several research projects relating to the function of controlling the stabilization of landfill waste, a key function of CSDFs. Specifically, we have adopted the method of watering to wash out organic contaminants in the bottom ash that comprises landfill waste. We discuss the effects that watering has on stabilization. We also report on watering methods to promote this stabilization and present ideas to determine the optimum watering method to achieve stabilization.

2 WASTE STABILIZATION

The phrase "waste stabilization" has various meanings. Generally, waste stabilization is a process in which organic matter in solid waste is degraded to carbon dioxide and water or where hazardous compounds are degraded or immobilized. However, while one may say that the stabilized state is a state where all pollutants in landfill waste are completely degraded or immobilized, it is in practice impossible to meet this requirement. In other words, there is a gap between actual and ideal situations in waste stabilization.

This study discusses waste stabilization from a realistic viewpoint, so we set the level of waste stabilization as the "abolishment standard", which is stipulated by the Japanese government. For example, if the quality of leachate meets an effluent standard or a local standard, the operation of a leachate treatment facility can be stopped.

In this study, an analytical method to promote waste stabilization was proposed to meet the abolishment standard, especially the standard for quality of leachate. We focused on bottom ash, which in Japan is usually disposed of by landfilling, and propose water leaching as the method to promote waste stabilization.

3 LANDFILL WASTE AND STANDARD IN JAPAN

3.1. Quality of landfill waste

In recent years, the composition of waste accepted by landfills in Japan has been changing, as shown in Figure 1. More than half (54% or 5,682,000 t) of the total mass of landfill waste in the 2000 fiscal year was incineration ash. The ratio of incineration ash to the total amount of landfill waste increased with time, because increasing proportions of the combustibles have been incinerated prior to landfilling and because recycling of incombustibles has been promoted. Therefore, this study focused on bottom ash as the subject of research.

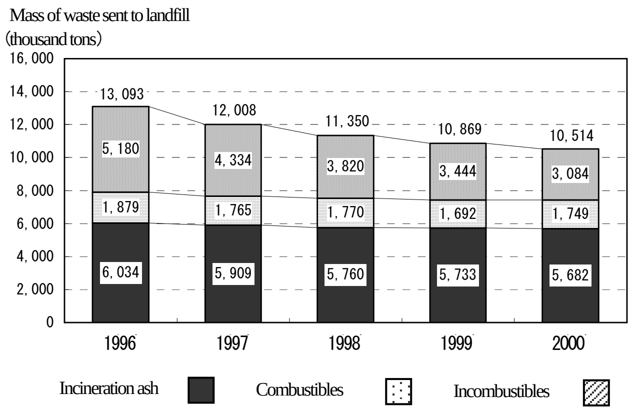

Figure 1 Changes in the Mass of waste sent to landfill

3.2. Standard for termination of operation and maintenance of landfill sites

The standard that defines the quality of leachate for termination of operation and maintenance of controlled landfill sites in Japan is "the quality of the leachate collected into the leachate collection pipe must meet the effluent standards for two years; (a) all compounds in effluent standard every six months; and (b) BOD (60 mg/L), and COD (90 mg/L) and SS (60 mg/L) every three months."

With regard to aspects other than leachate, there are standards that specify the temperature, gas emission rates and settling of the waste layers.

4 FACTORS INFLUENCING CHANGES TO PHYSICAL PROPERTIES OF LANDFILL WASTE

To achieve control of the elution velocity of various substances in landfill waste, it is necessary to confirm the effects various actions have in altering the physical properties of waste. It is important to utilize the information obtained to estimate what types of factors affect stabilization. As shown in Figure 2, we have postulated correlations between factors affecting waste (bottom ash) in the landfill layers and multiple leachate constituents in three scenarios, (a), (b) and (c). We describe the dominant factors influencing elution from bottom ash.

4.1 Factors influencing physical properties of landfill waste

(1) Landfill waste

As shown in Figure 2(a), landfill waste exhibits variable elution behavior in response to watering due to the following factors. Specifically, factors (a1) through (a4) are involved. (a1) "Various forms of pretreatment of landfill waste and

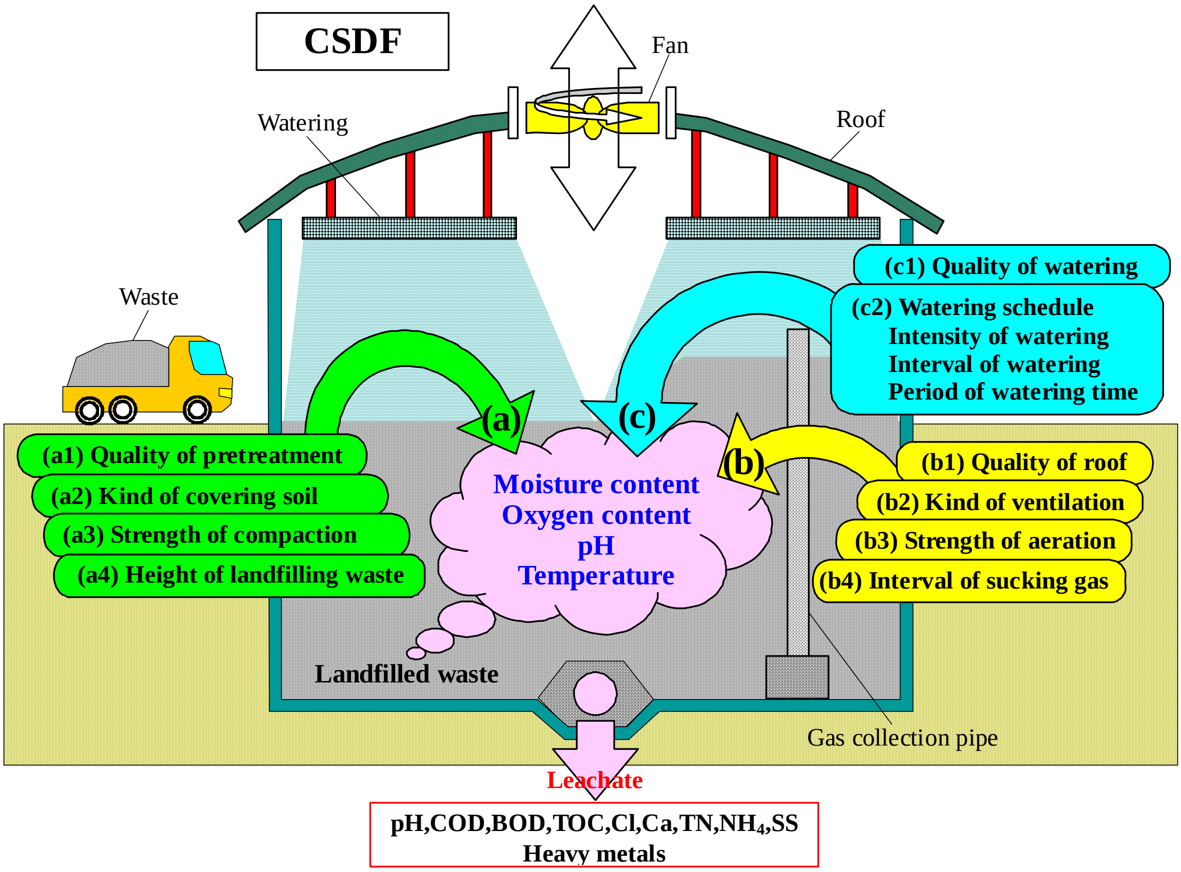

Figure 2 Factors affecting changes in properties of landfill waste

placement of additives in landfill waste," factors related to intermediate treatment prior to transportation of waste to the landfill site; (a2) "Quantity and quality of earth covering," factors related to earth-covering operations to prevent dispersal of landfill waste; (a3) "Location and order of disposing of landfill waste," factors related to the compacting of waste during landfill operations; (a4) "Height of landfilling waste," factors related to concentrations of some elution materials.

(2) Structure and specifications of landfill facility

As shown in Figure 2(b), landfill waste exhibits variable elution behavior in response to watering depending on factors related to the structure of the landfill site and equipment installed at the facility. Specifically, factors (b1) through (b4) are involved. (b1) "Roofing material used at landfill site," a factor related to roof structure, which influences the temperature of the landfill waste; (b2) "Frequency of ventilation and number of ventilation spots," a factor related to the method of ventilation used at the site, which influences water evaporation from the landfill layers; (b3) "Presence of gas collection pipes and location and number of gas-drainage pipes installed," a factor related to the method of supplying air to the landfill layers, which influences the atmosphere inside the landfill layers; (b4) "Interval of sucking gas," a factor related to the control method of the evolved gas from the waste which affects chemical degradation and microbial degradation of landfilled waste.

(3) Watering

As shown in Figure 2(c), landfill waste exhibits variable elution behavior in response to watering depending on factors related to the method of watering. Specifically, factors (c1) and (c2) are involved. (c1) "pH, salt concentrations and temperature of water used for watering," a factor related to the quality of water used in watering; (c2) "Intensity, Interval of watering and Period of watering time," a factor related to watering schedule.

4.2 Main influence and operation factors used in score table

In this study, we tried to develop a score table to extract the more important factors from all those possible factors that have effects on waste stabilization. We constructed the table by having 10 people carry out a paired-comparison of all factors and recording the level of correlation, from 0 to 2, of the answers. For example, the amount of water supplied and the amount of pollutants (inorganic substances) washed out by watering are strongly correlated, so the answer is 2. On the other hand, the structure of the roof of a CSDF and the amount of pollutants (inorganic substances) washed out by watering are not correlated, so the answer is 0. The landfill waste is assumed to be bottom ash.

The following information was extracted from the table.

- The more important operational factors were amount of supplied water, watering schedule (period of watering, intensity of watering, and frequency of watering), quality of supplied water, air supply method, and whether there had been any pretreatment before landfilling.
- The more important causal factors, which are related to changes caused by operational factors in the characteristics of landfill waste, were moisture content and water-holding capacity of the landfill waste.
- The more important phenomena occurring in waste layers were biological or chemical degradation, quality of leachate (COD, BOD, TOC, etc.), and generation of heat and gas.

5 EXPERIMENTS ON WASTE STABILIZATION

In Japan, various kinds of experiment have been conducted on waste stabilization. These experiments are divided into three categories with regard to the experimental conditions, as shown below.

a. Aerobic or anaerobic conditions, which depend on the differences in an oxygen supply system.

b. Watering conditions (period of watering, intensity of watering, and frequency of watering).

c. Infiltration characteristics of water into the waste because of differences in degree of compaction.

Most of the experiments have been conducted at a laboratory scale of tens of centimeters, with pilot experiments at a scale of tens of meters.

6 PROPOSED WATERING METHOD USING A NUMERICAL MODEL

When the authors looked at methods of watering to elute substances in landfill waste, they first proposed a numerical model to simulate elution behavior after watering the relevant substances (hereafter referred to as a "washout model"). They then simulated quantitatively elution characteristics under various watering conditions using this model. Based on the results, they determined the watering method exhibiting the most effective elution behavior from among numerous watering patterns.

6.1 The idea behind the washout model

In the washout model, there are two phases in the unsaturated flow within the waste layers: a mobile phase in which liquid (water) is able to flow and an immobile phase in which liquid (water) is unable to flow. The model is based on what is called a "two-phase model" in which there is migration of dissolved substances caused by differences in concentration between the two phases. In our research, Ishii expanded this two-phase model by making allowance for diffusion within the solid phase (particles of landfill waste). As a result, it was possible to incorporate migration of dissolved substances from the solid phase to the immobile water phase in the washout model. The basic idea of the washout model is shown in Figure 3. As this figure shows, the model assumes that there is always an immobile-water phase (L1) surrounding a solid phase (S). It also makes the following assumption: eluted substances move from the solid phase (S) to L1 and the elution velocity is proportional to the concentration gradient between the two phases. Moreover, when there is migration of water as a result of watering, again there is movement of eluted substances from L1 to L2 at an elution velocity proportional to the concentration gradient between the two phases when the L1 phase comes into contact with the mobile phase (L2).

We define the activity from the start of watering (supply of water to the waste layer) to the termination of watering as the "watering period." Between any given watering period and the next watering period, there is a period in which watering is discontinued. In other words, watering is not continuous. At CSDFs, the fundamental approach to the management of watering is this type of intermittent watering. The non-watering interval is an important element in the effective transfer of eluted substances to the mobile phase. The reason is that during the non-watering interval, eluted substances seep from the solid phase (S) to the immobile water phase (L1) and accumulate in the immobile water phase. We think this is because of the phenomenon of increased concentration of eluted substances in the L1 phase.

Based on the above, the washout model can be regarded as a modeling of the phenomenon of migration of eluted substances during these intermittent periods, which is a

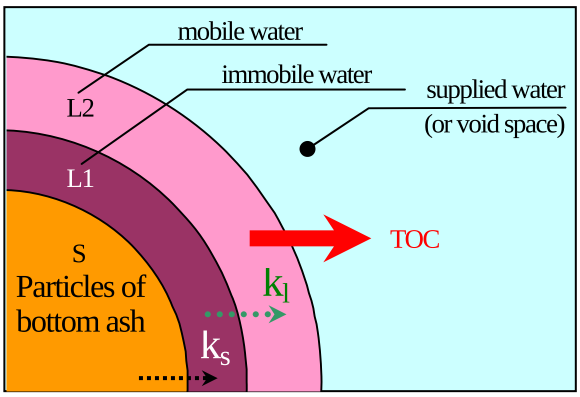

Figure 3. Idea of washout model

critical element when considering watering operations and effective elution of substances in a CSDF.

6.2 Check of the model

In order to validate the accuracy of the washout model, we conducted experiments using indoor column experimental equipment[1), 4)] on elution of TOC found in actual bottom ash under the watering conditions. We compared the experimental results obtained with the analytical results calculated from the washout model. We confirmed that as long as we can identify the appropriate parameters to input into the washout model, it is possible to simulate actual TOC elution behavior with this model.

6.3 Determination of watering method

Based on the experimental results and results of other experiments, by changing various watering conditions such as watering intensity, period and frequency of watering, different results are obtained in elution behavior for the same target object. Based on the results of this research to date, we define these three watering conditions as manipulated variables and the results obtained by changing each of these manipulated variables (the final cumulative volume of water required and amount of time to completion of watering) as the performance function. We view the watering pattern that optimizes (maximizes or minimizes) the performance function as the optimum watering method for the CSDF.

7 OPTIMIZATION OF STABILIZATION METHOD

If the various effects arising from differences in watering methods can be evaluated quantitatively, it should be possible to propose an optimum watering method for effectively eluting substances contained in waste in order to stabilize waste. When evaluating these effects, the choice of evaluation criteria, or evaluation function, to quantify the effects is important. What evaluation criteria (evaluation elements) should be included in the evaluation function to assess the optimal performance of multiple watering methods? Looking at it the other way, different evaluation criteria (evaluation elements) in the evaluation function could result in different optimum watering methods. Here we focused solely on "cost" in our evaluation. Specifically, of the various types of watering equipment that could be utilized to stabilize landfill waste, we assumed that the optimum watering method would be the one with the minimum total cost, when relative costs are compared for the largest water-treatment equipment, represented by an evaluation function comprising the sum of costs from the construction stage through the operation stage and the running stage. We present a specific example below.

7.1 Evaluation function

As shown in equation (7), total cost of water treatment (CT) (¥) used as an evaluation function is the sum of construction costs for water-treatment facilities (CI) (¥) plus running costs for the water-treatment facilities (CM) (¥). As shown in equation (8), CI is expressed as a relational expression consisting of volume of leachate treated Q_{day}[m^3/day] and coefficient of treatment capacity for the target substances to be treated KI[¥, day/m^3]. It varies, for example, depending on the number of target substances to be treated in a situation involving high-level processing, such as demineralization, when there is a large daily treatment volume. As shown in equation (9), Q_{day} is obtained from retardation factor R[-] taking into account watered area A[cm^2], watering intensity I[mm/h], watering period P[h], watering frequency F[1/day] and unsaturated flow of leachate in a vertical direction. As shown in equation (10), R is the time factor GV[sec] multiplied by seepage time obtained by dividing seepage velocity V[cm/sec] by the distance covered by seeping leachate H[m] from the watered surface to the bottom of the landfill.

As shown in equation (11), CM is the sum of running

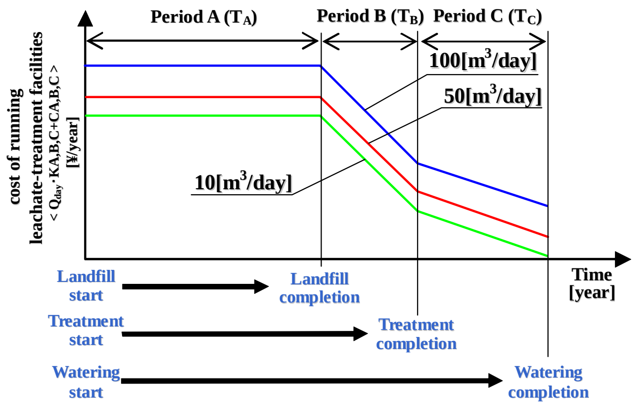

Figure 4 Relationship between duration and cost of running leachate-treatment facilities

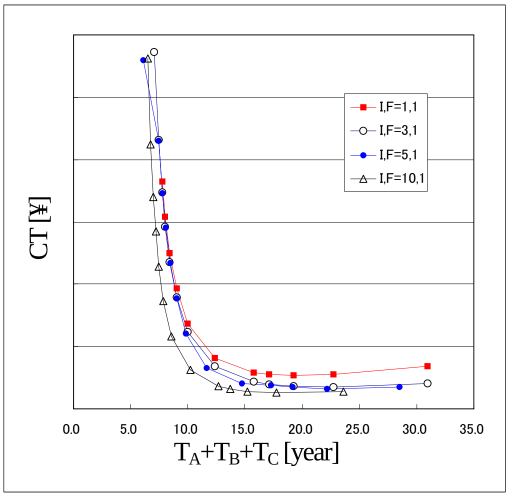

Figure 5 Relationship between CT and watering period

costs for leachate-treatment facilities (CMA) (¥) in landfill period A, running costs for leachate-treatment facilities (CMB) (¥) in demineralization period B, and administrative costs for leachate-treatment facilities (CMC) (¥) in the period of preparation for abolishment C. CMA•CMB•CMC are Q_{day} and running-cost coefficients KA•KB•KC[¥•day/year•m^3] for each period A–C and fixed running costs CA•CB•CC[¥/year] multiplied by watering period T_A•T_B•T_C[year], as shown in equations (12), (13), (14). The relationship shown in Figure 4 is an example. Regarding T_A•T_B•T_C, T_A is the landfill period while T_B and T_C are obtained from functions f_B•f_C used to calculate respective watering periods using R, I, P, F as variables, as shown in equations (15), (16). T_B and T_C obtained from functions f_B and f_C can vary substantially depending on the physical, chemical and biological characteristics of the target substances affected by watering as well as landfill conditions, and also by constraints on abolishment standards, such as permissible concentration, etc. Consequently, functions f_B and f_C cannot be regarded as established (universally applicable) calculation formulas at this point of time.

$$CT = CI + CM \qquad (7)$$

$$CI = Q_{day} \times KI \qquad (8)$$

$$Q_{day} = \frac{R \times A \times I \times P \times F}{1000} \qquad (9)$$

$$R = GV \times \frac{V}{H} \qquad (10)$$

$$CM = CMA + CMB + CMC \qquad (11)$$

$$CMA = (Q_{day} \times KA + CA) \times T_A \qquad (12)$$

$$CMB = (Q_{day} \times KB + CB) \times T_B \qquad (13)$$

$$CMC = (Q_{day} \times KC + CC) \times T_C \qquad (14)$$

$$T_B = f_B(R, I, P, F) \qquad (15)$$

$$T_C = f_C(R, I, P, F) \qquad (16)$$

7.2 Challenges for optimization

Figure 5 shows an example of a calculation of total cost of water treatment CT using different watering methods. These results show that simply shortening the watering period does not lower leachate-treatment costs. The likely reason for this is that construction costs CI are more dominant than running costs CM within CT. The precision of this result depends on the precision of the watering period (TB•TC) depending on differences in watering method (I, P, F) and the precision of running costs CM. Improving the level of precision is an issue to be addressed going forward. Another issue requiring further study is improvement of the evaluation function by the selection of cost elements apart from water-treatment costs and evaluation criteria apart from cost.

7.6 Future studies

In order to achieve practical application of a future optimization model, elements that should be taken into consideration (in addition to those mentioned above) are:

- Collection of data in other pilot-scale experiments
- Changing in characteristics of structure of bottom ash layer
- Elution phenomena of many components
- Simplification of model to design watering equipment
- Arrangement and analysis of T_B and T_C of measured data in existing landfill site.

8 CONCLUSIONS

This paper presents the results of basic research on factors influencing changes in properties of waste matter, the washout model, watering methods and relevant evaluation functions required for stabilization of landfill waste in a CSDF. These results are currently each independent of each other and we intend to pursue further research to improve the accuracy of the results and establish a design for watering methods to achieve greater stabilization.

This research has clarified the following.

1) The numerical-analysis model can predict quantitative TOC concentration in the pilot-scale experiments.
2) The optimization theory may possibly be applied to determine a watering method in the CSDF. An increase in the precision of the model is needed and requires collection of data in other pilot-scale experiments.
3) In this study, only the TOC concentration is considered. However, in actual situations physical, chemical and biological phenomena are related and each phenomenon is unsteady.

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