# RESEARCH ON A METHOD OF WASTE STABILIZATION CONTROL IN COMMUNITY AND CONTROLLABLE CLOSED SYSTEM DISPOSAL FACILITIES

**Yoshikazu Otsuka, Kazuei Ishii, Masataka Hanashima and Tohru Furuichi**
Working of fundamental investigation for waste stabilization,
Reserch group for control, Research Committee for Closed System Disposal Facilities
Chateau Takanawa 401, 3-23-14 Takanawa, Minato-ku, Tokyo 108-0074

## ABSTRACT

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 landfilled 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.

## INTRODUCTION

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 landfilled 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.

## QUALITY OF LANDFILLED WASTE IN JAPAN

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 landfilled waste in the 2000 fiscal year was incineration ash. The ratio of incineration ash to the total amount of landfilled

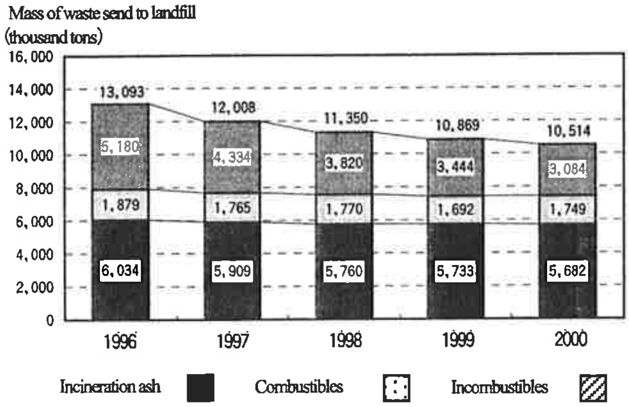


Figure 1 Changes in the Mass of waste sent to landfill

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.

## CONCEPT OF WASTE STABILIZATION

### The concept of stabilized condition

In general, landfilled waste contains some pollutants that have a harmful influence on human health or the environment. "Ultimate stabilization" in landfilled waste means the condition in which the pollutants in waste are completely kept within the landfill site or where the waste no longer contains pollutants. In addition, many kinds of phenomenon (e.g., physicochemical and biological phenomena) occur in landfilled waste until the landfilled waste is stabilized. To change landfilled waste into the ultimate stabilized condition is too expensive. This study did not deal with the ultimate stabilization of waste but a degree of waste stabilization based on Japanese law regarding termination of operation and maintenance of landfilled sites.

### Standard for termination of operation and maintenance f landfill sites in Japan

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.

## FACTORS INFLUENCING CHANGES TO PHYSICAL PROPERTIES OF LANDFILLED WASTE

In order to influence the stabilization of landfilled solid waste, it is important to check "by what kind of action" waste performs various kinds of changes in its physical properties; i.e., "what kind of factor influences stabilization".

### Factors influencing changes to physical properties

In order to study changes in physical properties of landfilled waste in the CSDF, factors that might influence changes in landfilled waste were investigated. In addition, the main factors peculiar to CSDFs were identified.

**Factors that influence the quality of waste:** These factors are (a) an intermediate treatment, such as incineration, before landfilling, (b) the compaction of the landfilled waste, and (c) the daily cover soil.

**Factors influenced by use of a CSDF:** The factors that influence waste inside a CSDF are (a) the ventilation method used in the CSDF, (b) the roof structure, which may have an effect on temperature in CSDF, and (c) the supply of air and water to the waste layer.

**Operational factors within the CSDFs:** These include, with regards to watering, (a) the amount of water used, (b) watering schedules, such as the period and frequency of watering, (c) the quality of the water, such as pH and concentration of salts, and (d) the temperature of the water.

### Main influence and operation factors for promoting waste stabilization

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 landfilled 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 landfilled waste, were moisture content and water-holding capacity of the landfilled 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.

## 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.

## THE WASHOUT MODEL AND AN EXAMPLE OF ANALYSIS OF BOTTOM ASH

A numerical model simulating elution of TOC from bottom ash has been developed. Although various models have been proposed, the washout model proposed by Ishii (Ishii et al., 2003) has been adopted and its application to the pilot-scale experimental results are described.

### Washout model

The washout model proposed by Ishii is based on the concept of a two-phase model, where one of the phases is a mobile water phase, which flows in void space. The other phase is an immobile water phase, which does not move and covers the particles of bottom ash. Ishii extended this two-phase model to three phases by incorporating mass transfer from a solid phase to the immobile water phase, including diffusion within the particle.

A schematic representation of the washout model is shown in Figure 2. The equations constituting the model are shown below. This model simulates vertical water flow (unsaturated water flow) in the unsaturated waste layer and the consequent change of TOC concentration in the leachate.

<The equation of washout model>

a. Water balance

One-dimensional unsaturated water movement in a bottom ash layer is represented, by Klute's equation, as follows:

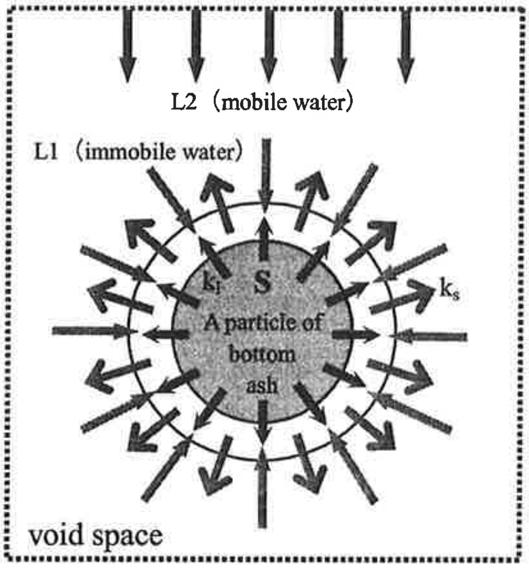


Figure 2. Representation of washout model

$$\frac{\partial \theta}{\partial t} = -\frac{\partial q}{\partial z} \tag{1}$$

$$q = -D(\theta)\frac{\partial \theta}{\partial z} + k(\theta) = -k(\theta)\frac{\partial h}{\partial \theta}\frac{\partial \theta}{\partial z} + k(\theta) \tag{2}$$

where $\theta$ is the volumetric water content, [–],$q$ is the Darcy velocity [L/T], $k$ is an unsaturated permeability for the water [L/T], $D$ is a capillary diffusivity [$L^2$/T], $h$ is the matrix potential [L], and $t$ is time [T].

b. Mass balance of TOC constituents in the mobile water phase (L2)

The mass balance of TOC constituents in the L2 phase is represented by advection-dispersion and mass transfer between the L2 and L1 phases.

$$\theta_{L2}\frac{\partial C_{L2}}{\partial t} = -q\frac{\partial C_{L2}}{\partial z} + \frac{\partial}{\partial z}(D_z\frac{\partial C_{L2}}{\partial z}) - k_l\theta_{L1}(C_{L2} - C_{L1}) \tag{3}$$

$$D_z = -D^0\frac{\theta_{L2}}{\xi} + M^0\frac{q}{\theta_{L2}} \tag{4}$$

where $C_{L1}$ represents the concentration in the L1 phase [$M/L^3$], $C_{L2}$ represents the concentration in the L2 phase [$M/L^3$], $D_z$ is a dispersion coefficient [$L^2$/T], $k_l$ is defined as a washout coefficient between the L2 and L1 phases [1/T], $D^0$ is an effective molecular diffusion coefficient [$L^2$/T], $\xi$ is a tortuosity factor [–], and $M^0$ is the dispersivity [L].

c. Mass balance of TOC constituents in the immobile water phase (L1)

Mass transfers between the S and L1 phase, and the L1 and L2 phases, are represented, respectively, as follows.

$$\frac{\partial C_{L2}}{\partial t} = -k_l(C_{L2} - C_{L1}) - k_s(C_{L1} - 10^{-3} f C_s) \tag{5}$$

where $k_s$ represents a diffusion coefficient from the S to L1 phases [1/T], and $f$[$M/L^3$] is defined as a conversion factor from TOC concentration in the S phase to that in the L1 phases. In other words, the factor $f$ is an inverse number of a product of a thickness of the water film [L] and a specific surface area [$L^2$/M] defined as a contact area between the S and L1 phases.

The mass transfer due to diffusion in the L1 phase is neglected, because the difference in TOC concentration is expected to be small.

d. Mass balance of TOC constituents in the solid phases (S)

In the S phase, the mass transfer between the S and L1 phases is represented as follows.

$$\frac{\partial C_s}{\partial t} = -k_s(C_s - \frac{10^3}{f}C_{L1}) \tag{6}$$

**Application of the model to a pilot-scale experiment**

A pilot-scale watering experiment was conducted as shown in Figure 3.

This experiment is the largest in a CSDF in Japan and is conducted under various kinds of conditions by Fukuoka University, Fujita Corporation and Mitsui Mining Co. Ltd.

The amount of water supplied per day was 750 L and the period of watering was 15 minutes.

Figure 4 is an example of the curve fitting of the washout model to experimental data. It was found that the calculated value could simulate the experimental results adequately when $k_l$ was set from 0.01 to 0.02.

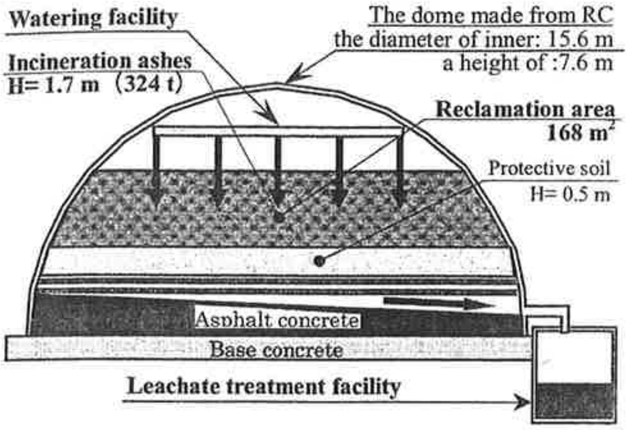


Figure 3. Pilot-scale watering experiment

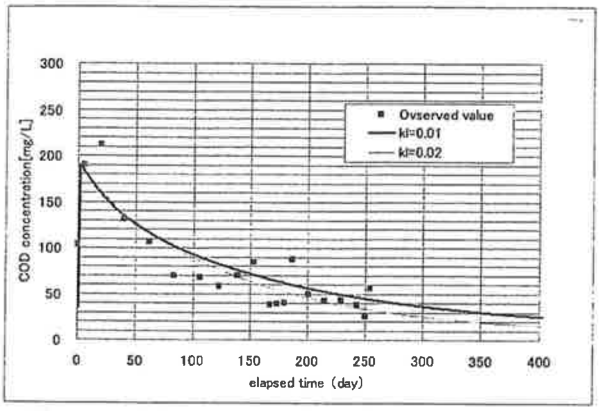


Figure 4 Relation between pilot-scale experimental result and washout model

Therefore, in order to obtain high-precision predictions, it is desirable to determine a parameter like $k_l$ from prior experiments using actual bottom ashes.

## APPLICATION OF OPTIMIZATION THEORY TO STABILIZATION CONTROL

Optimization theory was applied to the stabilization of a bottom ash. A problem was set as "to determine a method of watering a bottom ash layer to optimize cost and time until termination of operation and maintenance of landfill sites based on Japanese law". A possible solution is shown below.

### The scope of the control method

In order to control waste stabilization, it is necessary to determine a control system. A schematic representation of the control system is assumed to be as shown in Figure 5.

It was assumed that landfilled waste is separated from such external environmental factors as sun, thunderstorms and snow. In addition, the permeability of the waste layer is given. A controlled variable is the concentration of TOC in the leachate. Operating variables are the methods of water application, such as a frequency, intensity and period of sprinkling.

### Determination of operating variables

An operating variable is a variable that has an effect on an objective function. Therefore, a search is needed for a combination of operating variables so that the objective function becomes maximum or minimum. In this study, the following operating variables were set up.

＜Operating variables＞

The intensity of watering I(j), the period of watering k(m),

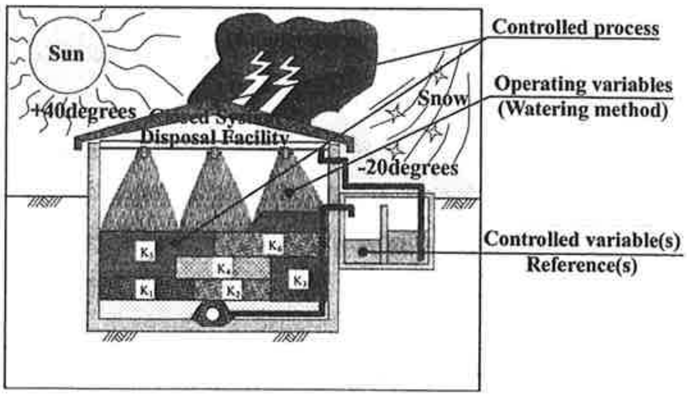


Figure 5 The global image of the control method

and the frequency of watering W(n) were set as operating variables. Each operating variable is changed in the range j = 1 to J, m = 1 to M and n = 1 to N. The effect of watering method on TOC elution in each case of combination (i = 1 – J*M*N), P(i) = {I (j), k (m), W (n)}, is evaluated.

**Objective function**

We define the elapsed time until the TOC concentration decreases to a desired value as Tend[day]. Tend is then a function of the watering method, as shown in Equation (6). An objective function is defined as the cost of the leachate treatment facility ($Z_{TOC}$), including construction and operational and maintenance costs, as shown in Equation (7). Minimization of $Z_{TOC}$ is needed while ensuring that the TOC concentration ($C_{TOC}$ [mg/L]) meets the effluent standard. It is noted that Japan does not have an effluent standard for TOC but does for COD and BOD. $C_{TOC}$ depends on the watering method. Therefore, $Z_{TOC}$ is the function of the watering method and an elapsed time of watering, as shown in a formula (7).

$$\mathrm{Tend} = f(P) = f(I,k,W) \tag{6}$$

$$Z_{TOC}(P,\mathrm{Tend}) = \mathrm{Cini}(Q) + \mathrm{Crun}(Q,\mathrm{Tend}) \tag{7}$$

Here, Cini is the construction cost [yen], and Crun is the operational and maintenance cost [yen] of a leachate treatment facility. As shown in Equation (8), Cini is a function of the intensity of watering I and the period of watering, time k; as shown in Equation (9), I and k are related to the amount of leachate to be treated Q (I, k) [$m^3$/day]. In addition, Crun is the function of the amount of leachate to be treated and an elapsed time of watering, as shown in Equation (10), and is the sum of the periodical maintenance and the fixation, plus the cost adjusted to the elapsed time of watering.

$$\mathrm{Cini}(Q) = \mathrm{Cini}(I,k) \tag{8}$$

$$Q(I,k) = A*I*k/1000 \tag{9}$$

$$\mathrm{Crun}(Q,\mathrm{Tend}) = \mathrm{Crun0}(Q) + Fc * \mathrm{Tend} \tag{10}$$

A: watering area [$m^2$]

Crun0: The operating cost of the leachate treatment facility [yen]

Fc: The cost of maintenance [yen/day]

Tend: Days of maintenance [day]

**Restriction conditions**

The restriction on the period of watering at one time was considered to be the maximum amount of watering on a day. The restriction on the intensity of watering was the limitation of the maximum intensity, which corresponds to the maximum infiltration rate of the waste layer. Other restrictions were limitation of the equipment for watering., etc.

**An analysis method by an optimization theory**

a. Pattern of the input data table for sprinkling-water

The sprinkling-water pattern in the example of application of the analysis result shown below determined the discretization of an input variable as follows, and created the table shown in Table 1. Sprinkling-water pattern P (i) becomes all the combination (7*7*7 = 343 pattern) of three operating variables from Table 1.

b. An example of application of an analysis result

The Q matrix of Table 2 was created from Equation (9) supposing that the area A of the sprinkling-water range is 1,000 square meters.

Table 1 Table of sprinkling-water pattern (operating variable)

| **Operating variable** | **Table column index** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **Intensity I (n) [mm／h]** | I(1) = 1 | I(2) = 2 | I(3) = 3 | I(4) = 4 | I(5) = 5 | I(6) = 6 | I(7) = 7 |
| **Period of watering k(m) [h／day]** | k(1) = 1.0 | k(2) = 1.5 | k(3) = 2.0 | k(4) = 2.5 | k(5) = 3.0 | k(6) = 3.5 | k(7) = 4.0 |
| **Frequency W(n) [day]** | W(1) = 1 | W(2) = 2 | W(3) = 3 | W(4) = 4 | W(5) = 5 | W(6) = 6 | W(7) = 7 |

Using this leachate throughput matrix, the sprinkling-water equipment cost in each sprinkling-water pattern was computed.

An analysis method to optimize the objective function is shown in Figure 6.

Table 2 Amount of leachate for one day

| Q [$m^3$/day] | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | | I(1) = 1 | I(2) = 2 | I(3) = 3 | I(4) = 4 | I(5) = 5 | I(6) = 6 | I(7) = 7 |
| 1 | k(1) =1.0 | 1.0 | 2.0 | 3.0 | 4.0 | 5.0 | 6.0 | 7.0 |
| 2 | k(2) =1.5 | 1.5 | 3.0 | 4.5 | 6.0 | 7.5 | 9.0 | 10.5 |
| 3 | k(3) =2.0 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 |
| 4 | k(4) =2.5 | 2.5 | 5.0 | 7.5 | 10.0 | 12.5 | 15.0 | 17.5 |
| 5 | k(5) =3.0 | 3.0 | 6.0 | 9.0 | 12.0 | 15.0 | 18.0 | 21.0 |
| 6 | k(6) =3.5 | 3.5 | 7.0 | 10.5 | 14.0 | 17.5 | 21.0 | 24.5 |
| 7 | k(7) =4.0 | 4.0 | 8.0 | 12.0 | 16.0 | 20.0 | 24.0 | 28.0 |

The calculated value of each objective function that resulted from this analysis is shown in Figure 7. The left figure (a) in Figure 7 means calculation results, relationship between the numerical value {$Z_{TOC}$(1) to $Z_{TOC}$ (343)} of the objective function and days of maintenance {Tend(1) to Tend(343)} in the case of watering method of 343 patterns{ P(1) to P (343)}. Similarly, the right figure (b) means rearrangement of calculation results. For example, when the optimization ranking is "Low", the numerical value of $Z_{TOC}$ is high. Conversely, when the optimization ranking is "High", the numerical value of $Z_{TOC}$ is low. Therefore, in this case, the optimal watering method serves as a point (the ranking of an objective function is the highest) of the rightmost end on a graph.

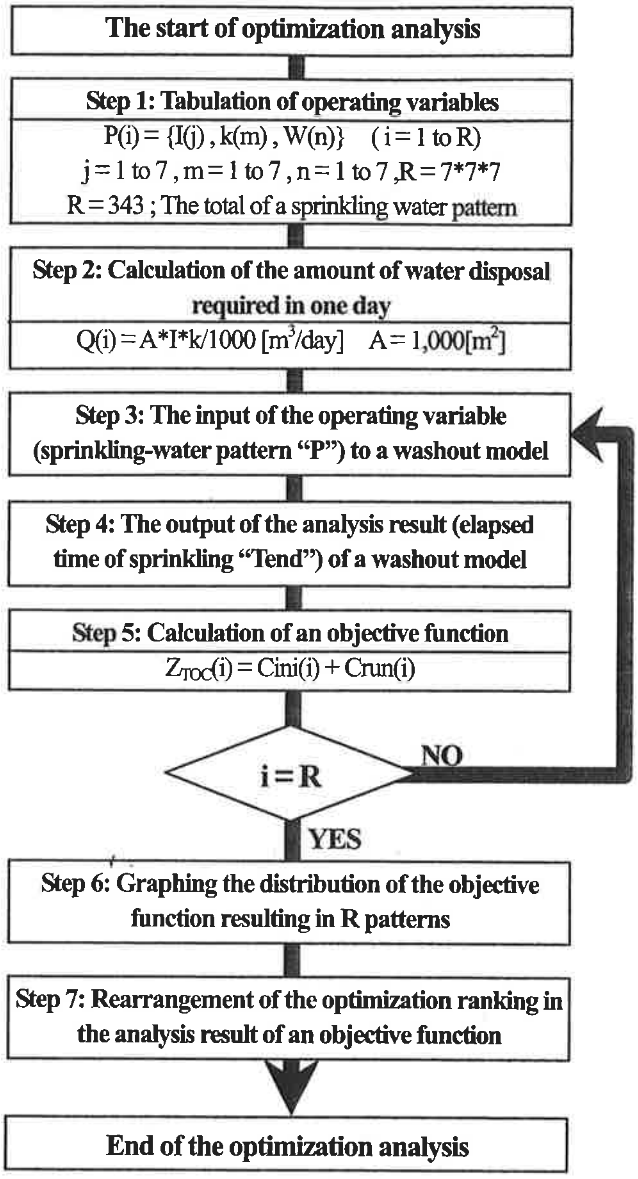
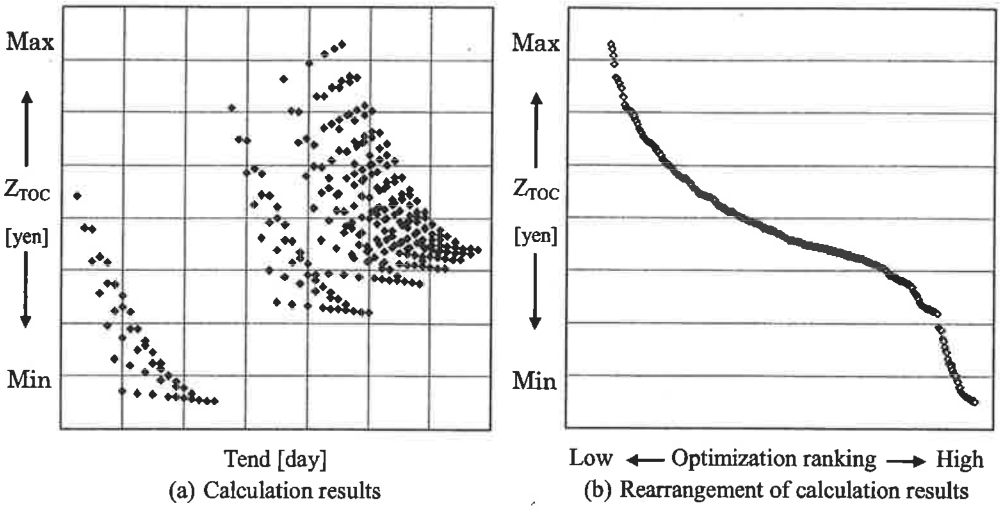


Figure 6 Flow of optimization

**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



(a) Calculation results (b) Rearrangement of calculation results

Figure 7 Distribution of objective function by sprinkling-water pattern

- The addition of the risk to the objective function
- Simplification of model to design watering equipment.

## CONCLUSIONS

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.

## ACKNOWLEDGMENTS

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