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(17) Study on optimum paths of sludge management - A conceptual approach

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ABSTRACT; This paper deals with an examination on a conceptual approach on optimum paths of sludge management. The contents are as follows: 1) A sewage treatment system as viewed from environmental system is presented for examining optimum paths of sludge management. 2) An analysis of cumulative proportion curve with respect to quantity of separated liquid is proposed. 3) Two methods using a multivariate analysis of variance for evaluating optimum condition of solid/liquid separation as viewed from a balance among various factors such as quantity and quality of water, sludge and energy are considered, and then a conceptual model with respect to optimum paths of sludge for its management is proposed.

KEY WORDS; conceptual approach, optimum paths, sludge, multivariate analysis of variance

1. Introduction

Everyday, a great amount of sludge is discharged from sewage treatment plants. The sludge is treated and disposed of by either land filling, incineration, or reclamation as resources(concrete aggregate, soil conditioners, etc.).

In the sewage treatment, although an attempt has usually been made toward the optimum design of the system, however, there are very few instances focusing on sludge management considering the balance among various factors, such as quantity and quality of sludge, quality of discharged water, energy input and output, as well as supply of stabilized sludge. Within an administration district, if the balance between supply and demand of resources and energy can be established, a new approach to reuse of sludge as heat source can be introduced.

In the present paper, as the first step toward the design optimization of sewage treatment system forcusing on sludge management, some representative treatment systems are examined, and an attention is paid especially to the system's solid/liquid separation process. Also, an analysis of cumulative proportion curve with respect to quantity of separated liquid is proposed. Furthermore, two methods using a multivariate analysis of variance for evaluating optimum condition of solid/liquid separation as viewed from a balance among various factors (such as quantity and quality of water and sludge, and energy) are considered. Finally, a conceptual model with respect to optimum paths of sludge for its management is proposed.

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2. Sewage treatment system as viewed from environmental system

At present, in the sewage collection for the public sewerage system in Japan, the separate system is adopted in 94 % of the city areas[1]. In the separate sewer system, the drainage from the storm sewer is directly discharged without treatment into the public water body. However, with the advancement of recent city activities, the wastewater consists of miscellaneous polluted materials, and thus the drainage from the storm sewer is quite polluted. This condition needs to be emphasized not only as a point source(eg., through sewage treatment plants), but also as a non-point source problem[2]. In the future, it will not be difficult to imagine that the situation of sewage influent will be quite complicated.

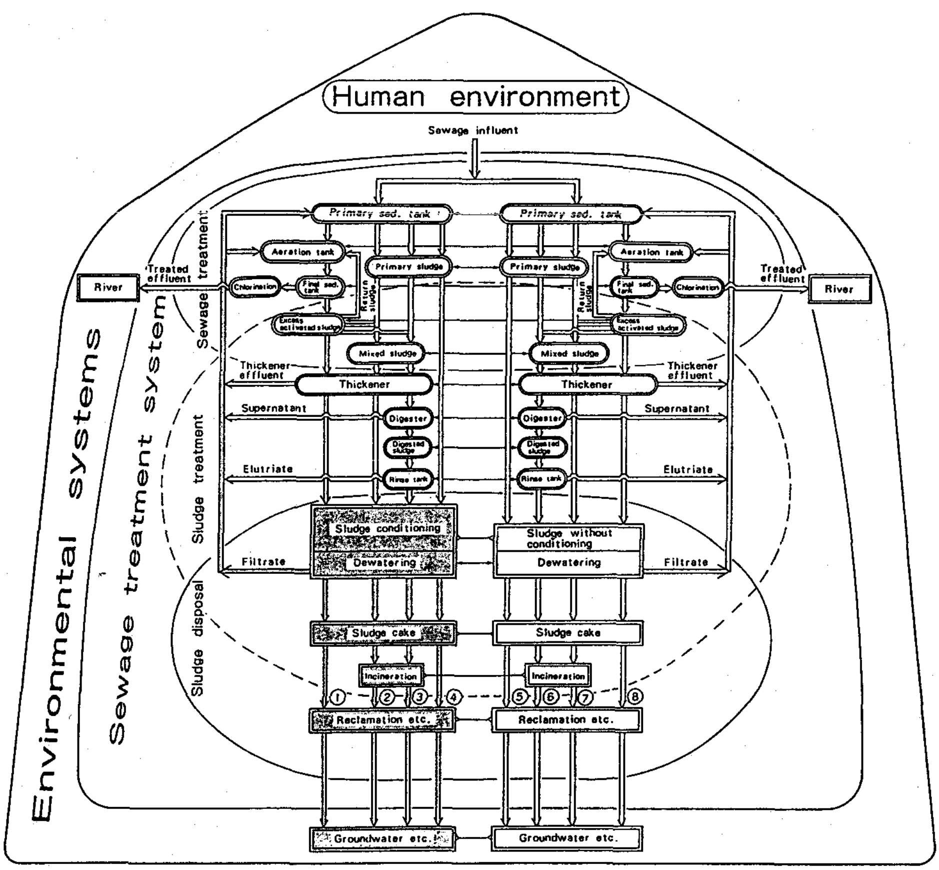

Fig.1 Flowsheet of sewage treatment as viewed from environmental systems

The flowsheet of current sewage treatment is shown in Fig. 1. In the flowsheet, the system is roughly divided into sewage treatment and sludge treatment, and both are further divided into various unit operations: grit settling, sedimentation, aeration, and chrolination in the former, thickening, digestion, dewatering, and incineration for the generated sludge in the latter. In general, in each subsystem, improvement of the efficiency of treatment in each process and operation has been emphasized. Until recently, it seemed to be of little importance that both sub systems are to be considered as one unit. However, as seen from Fig. 1, it is necessary that both sub system should be considered together as an intact sewage treatment system. The type of sludge generated from the sewage treatment system includes excess activated sludge, raw sludge, mixed sludge, and digested sludge. These sludges are generated by the 8 systems asshown in Fig. 1: the types of sludge with conditioning are shown on the left side((1) ~ (4)) and those without conditioning on the right side((5) ~ (8)). It is considered that sludge types with conditioning (on the left side) there are impacts on the natural ecosystem by the treated sludge because of the large amount of chemicals, such as slaked lime, ferric chloride and organic polymer, as well as odors from heat treatment of the sludge. The filtrate resulting from dewatering of the conditioned sludge is returned to the sewage treatment process. Moreover, the quality of sidestreams is generally bad[3]. Therfore, the return of the filtrate in the system is the reason for the deterioration in the treatment of the sewage.

On the other hand, in the four sludge types without conditioning (on the right side), the pretreatment such as chemicals addition and heat treatment are not performed. Therefore, it is suggested that in the sewage treatment system as viewed from a total environmental control, the sludge dewatering should be performed as shown on the right side of the system, which also makes the analysis easier.

However, in the current sludge dewatering practice in sludge treatment, sludge conditioning is mainly adopted. Therefore, it is important to determine optimum dewatering operational conditions with sludge conditioning in actual treatment plants. Before that for the simplicity, it is first of all necessary to grasp dewatering characteristics while without sludge conditioning.

3. Analysis of cumulative proportion curve with respect to quantity of separated liquid

In a previous paper[4], when using apparatus (pressure & vacuum filter) under the same experimental conditions, differences between the two filtration methods with respect to a balance among various factors such as quantity and quality of water and sludge and energy were recognized. In the present, the same model(Eq. (1)) is employed for evaluating a solid/liquid separation. By taking natural logarithms of both sides of the equation, Equation (1) becomes linear, as shown in Eq. (2).

$$V(t) = \alpha t^{\beta} \quad \text{where} \quad \alpha > 0, \quad 1 > \beta > 0, \quad t > 0 \qquad (1)$$

$$\ln V(t) = \alpha' + \beta \cdot \ln t \qquad (2)$$

From the two values(α , β) it is possible to predict the quantity of separated liquid at the arbitrary separation time.

In order to consider a balance among various factors such as quantity and quality of water and sludge, as well as energy for evaluating solid/liquid separation process in a sewage system, we here propose a cumulative proportion curve shown in Eq.(3).

$$P(t) = \frac{V(t)}{T} \tag{3}$$

where V(t): solid/liquid separation curve

T : total quantity of separated liquid

If we can define a cumulative proportion curve as mentioned above, the following two model are considered.

Logit transformation : $\ln\left(\frac{P(t)}{1 - P(t)}\right) = \alpha + \beta \cdot \ln t$

Complementary-log-log transformation : $\ln[-\ln(1 - P(t))] = \alpha + \beta \cdot \ln t$

By drawing the scatter diagram with respect to a relationship between ln t and y(t), we select a model which shows the stronger linear tendency.

4. Evaluation of solid/liquid separation in sludge using multivariate analysis of variance

Here we consider the two methods using a multivariate analysis of variance for evaluating the optimum condition of solid/liquid separation as viewed from a balance among various factors such as quantity and quality of water, sludge and energy. One is a five-way layout method , and the other is three-way one. The former is as follows. For convenience, the values of α' and β are shown as the notation of vector.
vector,

$$(\alpha' , \beta) = \chi_n \qquad n = 1, 2, \cdots\cdots, 32$$

The variation due to each separation factor and error can be calculated through the following formula.

$$S_1 = \frac{1}{32}(T_1 - T_2)(T_1 - T_2)' \tag{4}$$

where S_f = variation due to each dewatering factor A, B, C, D, G and E. (f = A, B, ···, G, A×B, A×C, ····, D×G, A×B×C, A×B×C, A×B×D, ···, C×D×G and E)

T_1, T_2 = total vector of data corresponding to the level 1 and 2 of the orthogonal array, respectively.

Using these values of variation obtained from Eq. (4), multivariate analysis of variance of the five-way layout method is conducted in the form as shown in Table 1[5]. The latter is a method using each mean vector. Using these values, a multivariate analysis of variance of the three-way layout method is conducted in the form as shown in Table 2[6].

By using these methods, we can compare the solid/liquid separation process considering various factors in each sewage treatment system mentioned above. Therefore, through a comparison of the separation process, we might be able to show an optimum path of sludge for its management.

5. Conclusion

A brief outline of the conceptual model with respect to an optimum path of sludge forits management is presented. And, the two evaluation methods of optimum condition of solid/liquid separation using multivariate analysis of variance are suggested.

Table 1. Multivariate analysis of variance of the five-way layout method

(1) Design of experiments

Factor A: 2 levels Factor B: 2 levels Factor C: 2 levels Factor D: 2 levels Factor G: 2 levels

Number of repetitions : 1 Data : 2-dimensions

(2) Multivariate analysis of variance

Factor	Sum of squares	Degree of freedom (ϕ_f)	Chi-square	Test standard
A	S_A	$1(=\phi_A)$	χ^2_A	$\chi^2_p(\alpha)$
B	S_B	$1(=\phi_B)$	χ^2_B	$\chi^2_p(\alpha)$
C	S_C	$1(=\phi_C)$	χ^2_C	$\chi^2_p(\alpha)$
D	S_D	$1(=\phi_D)$	χ^2_D	$\chi^2_p(\alpha)$
G	S_G	$1(=\phi_G)$	χ^2_G	$\chi^2_p(\alpha)$
A×B	$S_{A\times B}$	$1(=\phi_{A\times B})$	$\chi^2_{A\times B}$	$\chi^2_p(\alpha)$
A×C	$S_{A\times C}$	$1(=\phi_{A\times C})$	$\chi^2_{A\times C}$	$\chi^2_p(\alpha)$
A×D	$S_{A\times D}$	$1(=\phi_{A\times D})$	$\chi^2_{A\times D}$	$\chi^2_p(\alpha)$
A×G	$S_{A\times G}$	$1(=\phi_{A\times G})$	$\chi^2_{A\times G}$	$\chi^2_p(\alpha)$
B×C	$S_{B\times C}$	$1(=\phi_{B\times C})$	$\chi^2_{B\times C}$	$\chi^2_p(\alpha)$
B×D	$S_{B\times D}$	$1(=\phi_{B\times D})$	$\chi^2_{B\times D}$	$\chi^2_p(\alpha)$
B×G	$S_{B\times G}$	$1(=\phi_{B\times G})$	$\chi^2_{B\times G}$	$\chi^2_p(\alpha)$
C×D	$S_{C\times D}$	$1(=\phi_{C\times D})$	$\chi^2_{C\times D}$	$\chi^2_p(\alpha)$
C×G	$S_{C\times G}$	$1(=\phi_{C\times G})$	$\chi^2_{C\times G}$	$\chi^2_p(\alpha)$
D×G	$S_{D\times G}$	$1(=\phi_{D\times G})$	$\chi^2_{D\times G}$	$\chi^2_p(\alpha)$
A×B×C	$S_{A\times B\times C}$	$1(=\phi_{A\times B\times C})$	$\chi^2_{A\times B\times C}$	$\chi^2_p(\alpha)$
A×B×D	$S_{A\times B\times D}$	$1(=\phi_{A\times B\times D})$	$\chi^2_{A\times B\times D}$	$\chi^2_p(\alpha)$
A×B×G	$S_{A\times B\times G}$	$1(=\phi_{A\times B\times G})$	$\chi^2_{A\times B\times G}$	$\chi^2_p(\alpha)$
A×C×D	$S_{A\times C\times D}$	$1(=\phi_{A\times C\times D})$	$\chi^2_{A\times C\times D}$	$\chi^2_p(\alpha)$
A×C×G	$S_{A\times C\times G}$	$1(=\phi_{A\times C\times G})$	$\chi^2_{A\times C\times G}$	$\chi^2_p(\alpha)$
A×D×G	$S_{A\times D\times G}$	$1(=\phi_{A\times D\times G})$	$\chi^2_{A\times D\times G}$	$\chi^2_p(\alpha)$
B×C×D	$S_{B\times C\times D}$	$1(=\phi_{B\times C\times D})$	$\chi^2_{B\times C\times D}$	$\chi^2_p(\alpha)$
B×C×G	$S_{B\times C\times G}$	$1(=\phi_{B\times C\times G})$	$\chi^2_{B\times C\times G}$	$\chi^2_p(\alpha)$
B×D×G	$S_{B\times D\times G}$	$1(=\phi_{B\times D\times G})$	$\chi^2_{B\times D\times G}$	$\chi^2_p(\alpha)$
C×D×G	$S_{C\times D\times G}$	$1(=\phi_{C\times D\times G})$	$\chi^2_{C\times D\times G}$	$\chi^2_p(\alpha)$
Error	S_e	$6(=\phi_e)$		
T	S_T	$31(=\phi_T)$		

$\chi^2_f = -m\cdot\log_e \nu_f$

(f = A, B, C, D, G, A×B, ········, D×G, A×B×C, ········, C×D×G)

$m = \phi_e - \frac{1}{2}(p - \phi_f + 1)$

$\nu_f = \frac{|S_e|}{|S_f + S_e|}$

Table 2. Multivariate analysis of variance of the three-way layout method.

(1) Design of experiments

Factor A : ℓ levels Factor B : m levels Factor C : n levels

Number of repetitions : 1 Data : p-dimensions

(2) Multivariate analysis of variance

Factor	Variation(S_f)	Degrees of freedom(ν_f)	Chi-square	Test standard
A	S_A	$\ell-1$	χ^2_A	$\chi^2_{p(\ell-1)}(\alpha)$
B	S_B	$m-1$	χ^2_B	$\chi^2_{p(m-1)}(\alpha)$
C	S_C	$n-1$	χ^2_C	$\chi^2_{p(n-1)}(\alpha)$
A×B	$S_{A\times B}$	$(\ell-1)(m-1)$	$\chi^2_{A\times B}$	$\chi^2_{p(\ell-1)(m-1)}(\alpha)$
B×C	$S_{B\times C}$	$(m-1)(n-1)$	$\chi^2_{B\times C}$	$\chi^2_{p(m-1)(n-1)}(\alpha)$
A×C	$S_{A\times C}$	$(\ell-1)(n-1)$	$\chi^2_{A\times C}$	$\chi^2_{p(\ell-1)(n-1)}(\alpha)$
E	S_e	$(\ell-1)(m-1)(n-1)$		
T	S_T	$\ell mn-1$		

$\chi^2_f = -[(\ell-1)(m-1)(n-1) - \frac{1}{2}(p - \nu_f + 1)]\log_e \nu_f$

$\nu_f = \frac{|S_e|}{|S_f + S_e|}$ (f = A, B, C, A×B, B×C, A×C)

By using evaluation methods for solid/liquid separation through the multivariate analysis of variance, we can compare different separation processes considering various factors in each sewage treatment system.

Through a comparison of each separation process, we might be able to show an optimum path of sludge for its management in the future.

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