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SIMULATION OF THE OPERATIONAL CONDITIONS OF WASTEWATER TREATMENT PLANTS TO MAXIMIZE ENERGY RECOVERY

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INTRODUCTION

The recent movement for protecting the global environment requests wastewater treatment plants to have functions not only of the wastewater treatment but also of the heat energy recovery from the wastewater. Ochifuji et al. (1992) paied attention on the temperature of the effluent and studied heat recovery from the effluent. The heat energy recovery by sludge becomes one of the purposes of the plant operation. It is required to study the relation between energy based performance of plant and operation. This energy based approach makes us to consider how to treat and recycle the waste heat and organic matters in the urban system. The objectives of this paper are 1)to summarize the heat energy flow through the water supply and sewage system by computing heat value of sewage and sludge from plant data 2)to investigate the controllability of heat energy recovery by simulating plant performance using the activated sludge model.

HEAT ENERGY ANALYSIS OF THE WASTEWATER TREATMENT PLANT

Calculation of heat value of sewage and cake Heat value of an influent and an effluent as well as cake should be estimated from data of a plant: temperature, COD or BOD concentration and organic and water contents of cake. In the present study, heat value of sewage and cake are evaluated by sensible heat and a heat of the oxidative reaction. The heat of the oxidative reaction is corresponding to the generated heat when organic matters are oxidized to the water and carbon dioxide. The heat value of cake can be calculated by subtracting latent heat of water in cake from this heat of the reaction.

Calculation of sensible heat. Since the amount of utilizable heat energy depends on the ambient air temperature, the mean temperature of the atmosphere at each month is used for the sensible heat calculation.The sensible heat of unit volume sewage, q (J/m^3) can be estimated by

$$q = C_P \times \rho \times (T - T_0) \tag{1}$$

where C_P is the specific heat (4.1868KJ/kg/K in this study), ρ is the density of the sewage ($1000kg/m^3$) , T is the temperature of sewage and T_0 is the mean temperature of the atmosphere.

Calculation of heat value of cake. Murakami et al. (1986) collected data of heat values of cakes from many plants in Japan, and proposed the following empirical formulas:

$$H_h = 58.3 \times X_{CAKE} - 193, \qquad H_C = (1-w/100)\left(0.93\left(\frac{H_h - 353(k_2 - 0.69k_1)}{1 + k_2 - 0.03k_1}\right) - 33\right) - 540w/100 \tag{2}$$

where H_h is the heat value of organic matters in cake (kcal/kg-DS in cake), H_C is the heat value of cake (kcal/kg-cake), X_{CAKE} is the organic matter content in cake (%), and k_1 and k_2 are respective addition rates of ferric chloride and lime, respectively.

Calculation of heat value of organic matter in sewage. Goda et al. (1974) studied the relation between BOD and change of enthalpy in oxidative reaction, and they proposed the following relationship:

$$H_0 = (BOD/0.146) \times 4.1868 \times 10^3 \tag{3}$$

where H_O is the heat value of organic matters in sewage (J/m^3) and the unit of BOD is g/m^3.

The Investigated Plant Calorimetric evaluation was carried out for the wastewater treatment plant in Sapporo. This plant treats about 9500m^3/day of wastewater on a dry weather day. This plant has two lanes in its water treatment system, and one sludge treatment system. Each water treatment lane has primary clarifiers, aeration basins and final clarifiers. The sludge treatment system has gravity thickeners and pressure filtration units. The 80% of cake from the plant are incinerated. Plant data from April 1990 to March 1991 were used in the present study

Increase in Sensible Heat of Sewage Figure 1 shows that there are two peaks, in summer and in winter, in the variation of the sensible heat gained in the plant. The increase in sensible heat may depend on the oxidation of organic matters in the aeration basin and on the power consumption by the blowers and pumps in the plant. The amount of increase in the sensible heat calculated by the temperature difference was compared with the computed result by summing the energy consumption of facilities and the amount of oxidized organic matters in Table 1. I t can be seen from Table 1 that the error between the two computed values are less than 10% except for in winter, and that increase in sensible heat is due to the biological reaction in the aeration basin.

Table 1 INCREASE OF SENSIBLE HEAT, ENERGY CONSUMPTION AND OXIDIZED ORGANIC MATTER (J/day)

Month	(1)increase of sensible heat	(2)energy consumption ×0.6	(3)oxidized organic matter	(4)=(2)+(3)	error ((1)-(4))/(1)
APL	3.42×10^{11}	6.03×10^{10}	2.33×10^{11}	2.93×10^{11}	0.14
MAY	3.37×10^{11}	5.93×10^{10}	2.94×10^{11}	3.53×10^{11}	-0.05
JUN	3.96×10^{11}	6.24×10^{10}	3.12×10^{11}	3.74×10^{11}	0.05
JUL	4.45×10^{11}	6.33×10^{10}	3.92×10^{11}	4.56×10^{11}	-0.03
AUG	4.58×10^{11}	6.53×10^{10}	3.77×10^{11}	4.42×10^{11}	0.03
SEP	3.73×10^{11}	6.55×10^{10}	3.74×10^{11}	4.39×10^{11}	-0.18
OCT	3.39×10^{11}	6.30×10^{10}	2.87×10^{11}	3.50×10^{11}	-0.03
NOV	3.70×10^{11}	6.42×10^{10}	2.71×10^{11}	3.35×10^{11}	0.09
DEC	3.55×10^{11}	6.77×10^{10}	3.01×10^{11}	3.68×10^{11}	-0.04
JAN	4.36×10^{11}	6.74×10^{10}	2.78×10^{11}	3.45×10^{11}	0.21
FEB	4.63×10^{11}	6.68×10^{10}	2.66×10^{11}	3.33×10^{11}	0.28
MAR	4.76×10^{11}	7.23×10^{10}	3.52×10^{11}	4.24×10^{11}	0.11

Heat Value of Cake There are few variation in water content of cake in the plant as shown in Fig.2. The variation in the heat value of cake was caused by the change in the organic content in cake. The low heat value in August and September may be due to the higher sewage temperature and higher decomposition rate of organic matters than in other months. Figure 3 shows monthly variations in the cake production and the recovered calory by cake production. There is a close correlation between cake production and the amount of heat recovery. This means that the amount of heat recovery by cake depends mainly on the amount of the cake, and that the organic content of cake has small effect.

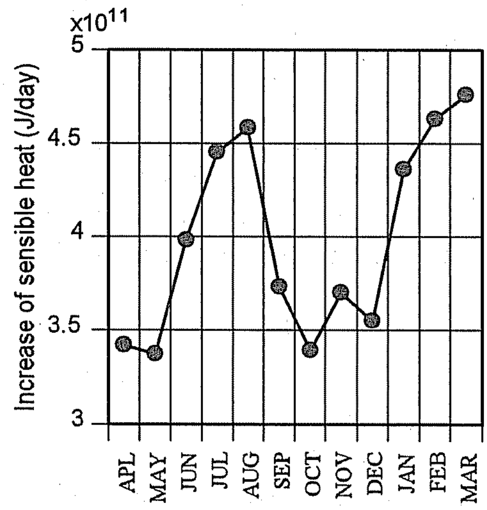

Fig.1 Increase of sensible heat

Total heat energy flow though the water system in Sapporo

Figure 4 shows the flows of water and heat energy in February, 1991. The values of water flow rate and heat energy in the figure are summation of four water purification plants and eight municipal wastewater treatment plants in Sapporo. The heat gain in facilities is larger in winter than in summer. About 34,000TJ of the heat energy is consumed annually in Sapporo, and the total amount of sensible heat in the effluent water is about 9,000TJ. The large amount of heat energy is wasted to the sewage. The total recovered heat energy is the sum of the increase of sensible heat energy in the plant and the heat value of cake. The efficiency of energy recovery in the plant is defined as: [efficiency of energy recovery]=[total recovered heat energy]/[electric power], this efficiency is about 1.75 in summer and 2.3 in winter. In this calculation we set that the efficiency of electric power generation is about 0.35.

The organic matters in the influent is distributed three outputs of a wastewater treatment plant: the effluent, cake and carbon dioxide gas. This process can be evaluated in terms of heat energy. The 60% in summer or 50% in winter of heat energy of organic matters in sewage is oxidized in wastewater treatment plant, and this oxidized

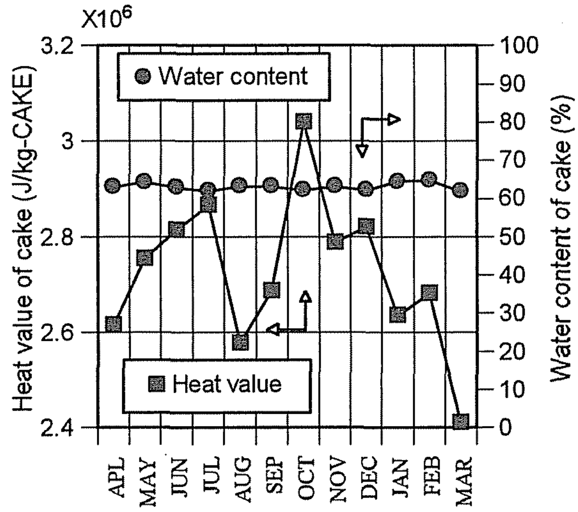

Fig.2 Heat value and water content of Cake

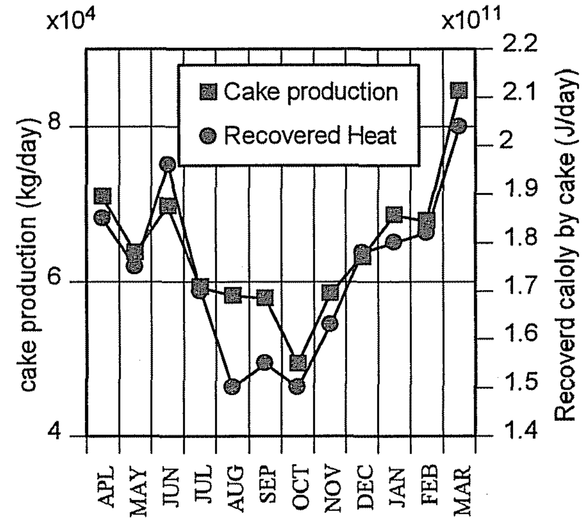

Fig.3 Cake production and heat recovery

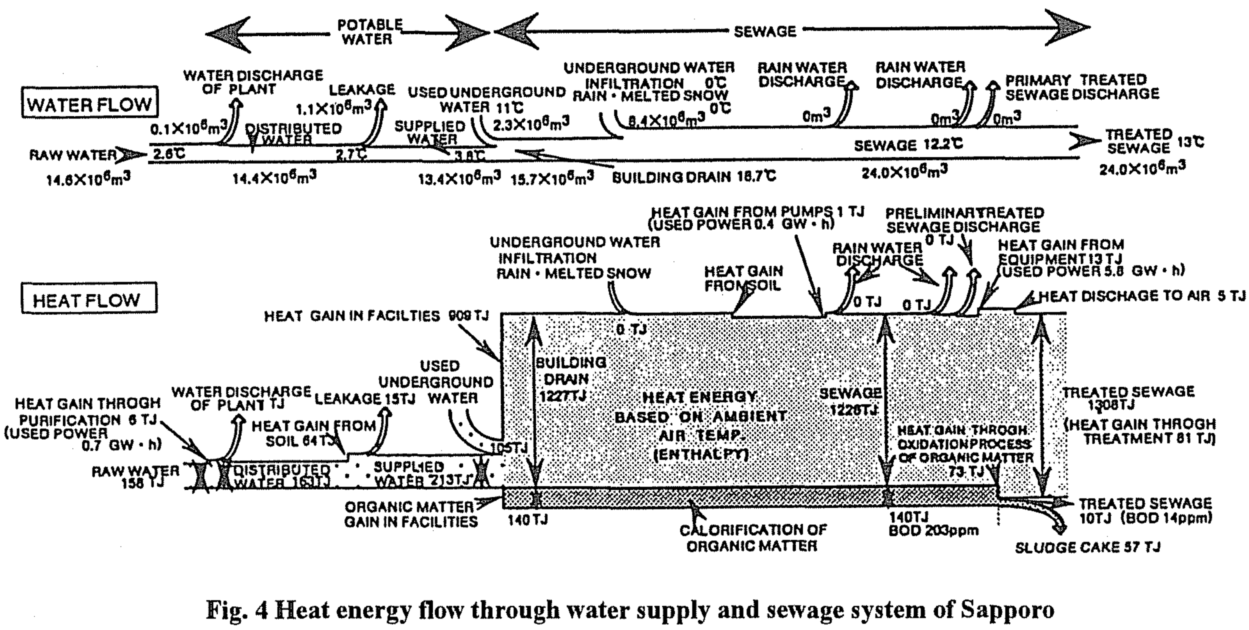

Fig. 4 Heat energy flow through water supply and sewage system of Sapporo

energy, 115TJ in summer or 73TJ in winter, turns out the sensible heat of water. The heat energy of cake is about 50TJ, and is smaller than sensible heat gain through oxidation process. There are two ways to recover heat energy from wastewater treatment plants, one is from swage as sensible heat and the other is from cake as burning heat. It is important to study the controllability of this energy distribution in treatment process by the plant operation.

SIMULATION

Model Used in the Simulation We used the model of the full scale municipal wastewater treatment plant at a steady state. Processes included in this model are those of primary clarifier, aeration basin, final clarifier, thickener and pressure filter. The Activated Sludge Model No.1 (Henze et. al., 1987) was used for simulation of reactions in the aeration basin. This model has been calibrated, and applicability of the model to the investigated plant has been also confirmed (Funamizu and Takakuwa, 1994). We adopted OUR measurement proposed by Kappeler and Gujer (1992) to characterize organic matters in the influent. The measured results are summarized in Table 2. In simulation, the effluent water quality and the organic content and mass production rate of cake were computed. Then heat energy values of effluent and cake were calculated by using eqs. (2) and (3). We simulated monthly variations of performance, and compared the computed results with plant data. The comparisons in Figs.5 and 6 show that the simulation yielded the reasonable results in evaluating heat energy.

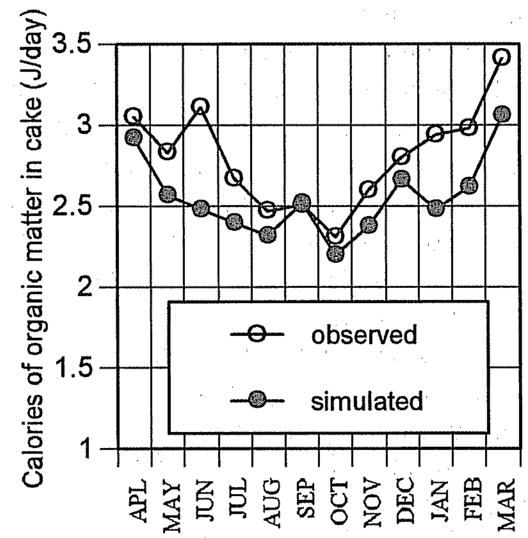

Fig.5 Comparison of computed results with plant data-1, Heat value

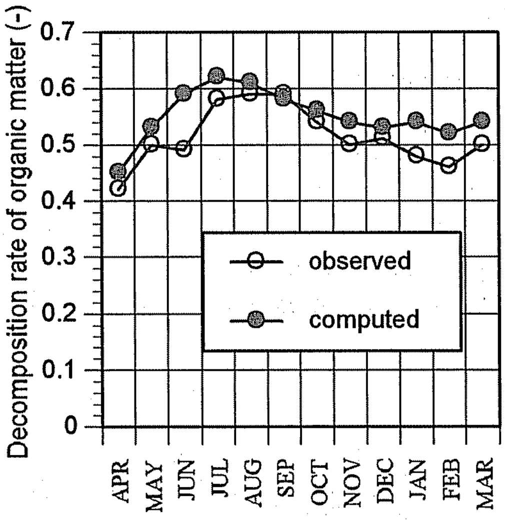

Fig.6 Comparison of computed results with palnt data-2, Decompositon rate of organic matter

Results of the Simulation Since the amount of heat energy recovered by cake depends on the decomposition of organic matters in a aeration basin, operational variables in the simulation were the sludge recycle rate R_s, (=[sludge recycle flow rate] / [sewage flow rate into the plant]) and the excess sludge withdrawal rate R_e, (=[excess sludge flow rate] / [sewage flow rate into the plant]) as well as the solid removal efficiency of the primary clarifier, r_{PC}. Simulation was carried out for the following operation:

Table 2 INFLUENT CONCENTRATIONS USED IN THE SIMULATION (g/m³)

Readily biodegradable COD	Soluble inert COD	Slowly biodegradable COD	Particulate inert COD	Heterotrophic biomass COD
20	18	150	35	20
NH_4-N	NO_x-N	Soluble Org-N	Particulate Org-N	non-volatile SS
18	0.3	5	4	60

Sewage flows into the aeration basin at three points. Distribution ratio is $Q_1:Q_2:Q_3=1:1:1$. The second and forth units of aeration basin are kept anoxic(Fig.7).The simulation results were evaluated by the following two variables: 1) total nitrogen removal efficiency, 2) heat energy of the organic matter in cake.

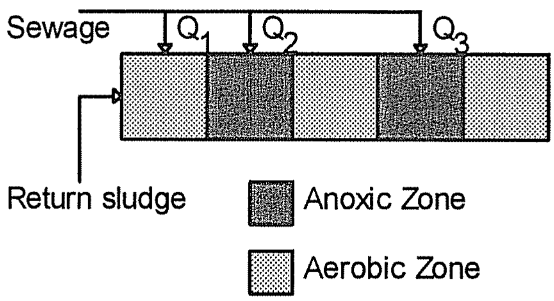

Fig.7 Simulated configration of aeration basin

The computed results when $r_{PC}=0.6$ are shown in Fig.8. In this operation, there is the optimum operational point to keep denitrification as well as to recover heat energy from cake. Figure 9 shows the effect of r_{PC} on the nitrogen removal and heat energy recovery. These plots were gathered by computing the optimal operational condition at respective value of r_{PC}. It can be seen from Fig.9 that

(1) The higher r_{PC} is, the more heat energy are recovered from cake.
(2) But, increase in r_{PC} causes the decrease in the nitrogen removal. This is why denitrification in anoxic zones is controlled by the amount of organic matter supplied by the effluent of the primary clarifier.
(3) there is the optimum solid removal efficiency of the primary clarifier to satisfy both nitrogen removal and heat energy recovery from cake.

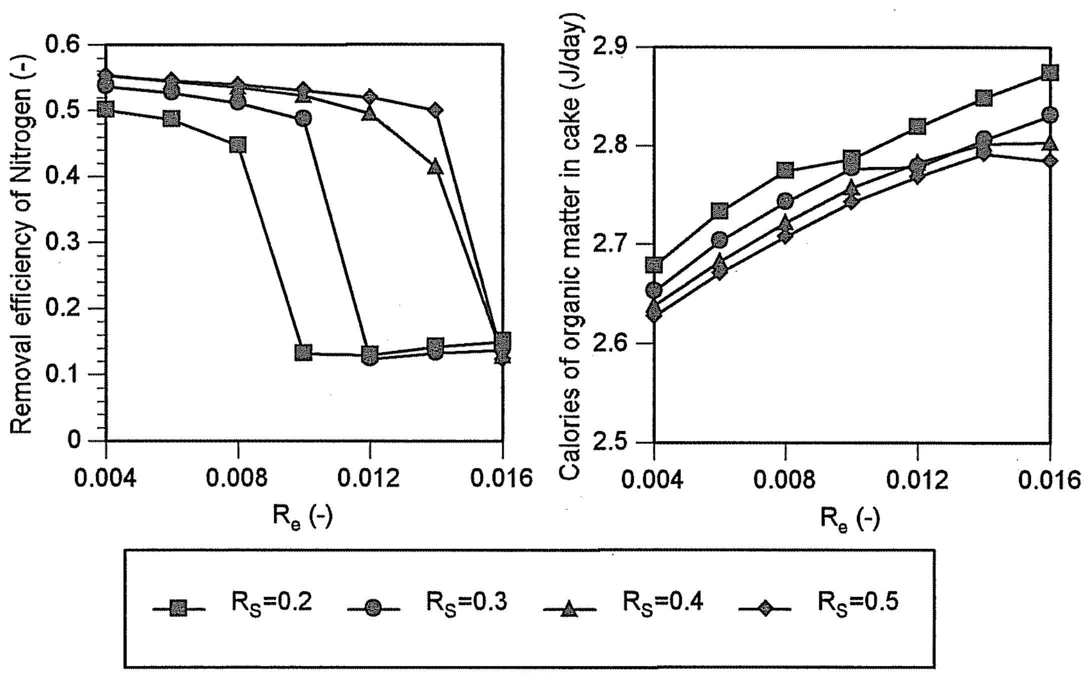

Fig.8 Simulated results

CONCLUSION

The procedure for evaluating the heat energy of sewage and sludge was proposed. The heat energy flow in Sapporo showed that the increase in sensible heat of sewage in the plant depended mainly on the amount of organic matters oxidized, and that about 55% of organic matter in sewage turned out the sensible heat. The full-scale plant model was able to simulate the heat energy of cake and the oxidation performance of organic matters. It was demonstrated by the full-scale plant model simulation that there was the optimum operation condition among sludge recycle, excess sludge withdrawal and solid removal efficiency of the primary clarifier to maintain effluent water quality level as well as to maximize heat energy recovery. Computed results also showed that there was the trade-off relationship between the total nitrogen removal and heat energy recovery from cake.

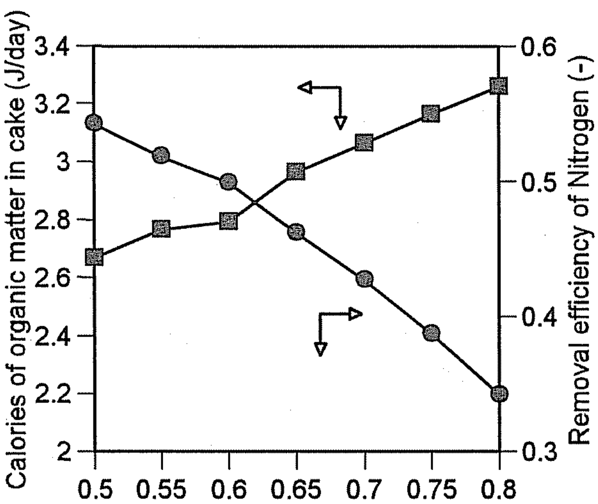

Fig.9 Effect of r_{PC} on heat value of cake and nitrogen removal

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