Disposal of Solid Waste in Developing Countries to Improve Environment

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開発途上国における環境改善のための廃棄物処理

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まず，一部の開発途上国における廃棄物及びその処理の現状について調査した．また，厨芥処理に適したコンポスト化について実験的に検討し，気体発生量等を明らかにした．ついで，これらの調査・実験結果及び廃棄物の物性値などを用いた計算により，対象とする地域の廃棄物に適したシステムの構築により，処分場への堆積量や温暖化ガスの発生量を低減できる結果を得た．以上より，本システムを開発途上国向けの廃棄物処理システムの一つとして提案した．

1. Introduction

MSW (Municipal Solid Waste) is landfilled without any treatment in most of the developing countries. The biogas and leachate generated from the landfilled MSW pollute air and water. Further, since the MSW is considerably increasing with the economic growth, it becomes difficult to make more site. It is, therefore, necessary to develop an alternative disposal system immediately.

To solve this problem, there are many studies on various techniques to dispose of MSW, e.g., composting, incineration, methanation, and so forth. However, almost all these studies deal with the performances of the respective techniques only and the study on the synthesis and the effect on the environment of the whole system composed of these techniques are quite few.

The purpose of this thesis is to develop a novel MSW disposal system for the developing countries improving both the regional and global environment.

2. MSW in developing countries

The compositions of the MSWs in some developing countries and Japan are compared in Table 1. Food, paper and plastics are major contents in MSW. The MSWs in the developing countries contain so much amounts of the food wastes that the methane emission rates from the MSWs landfilled are high and the MSWs cannot be incinerate easily.

Table 2 shows the disposal methods. The MSW disposal in the developing countries are depending on landfilling on the contrary with Japan, where the incineration is the most popular method.

In Kathmandu, Nepal, the gas emission and leachate from Gokarna landfill-site are the serious problem. In Bangkok, Thailand, it is quite difficult to obtain the space for the landfill close to the central of the city, and the transportations to landfill-sites are getting heavier.

Table 1 Three major contents in MSW[1]~[5]

city or nation	content [%] upper row : dry weight basis, lower row : wet weight basis			
	food	paper	plastic	moisture
Kathmandu	**87.8**	**5.4**	**6.8**	
	97.3	1.2	1.5	**77.8**
India	**46.7**	**31.9**	**21.4**	
	81.4	11.1	7.5	**65.1**
Shanghai	**38.2**	**22.3**	**39.6**	
	79.2	7.5	13.3	**66.4**
Bangkok	**48.6**	**19.1**	**32.3**	
	80.5	7.2	12.3	**62.0**
Tokyo	**20.1**	**53.2**	**26.7**	
	55.6	29.6	24.0	**44.4**
Kyoto	**17.4**	**58.0**	**24.6**	
	51.3	34.3	14.5	**41.0**

Table 2 disposal methods of MSW[2],[3],[6],[7]

city or nation	year	MSW disposal [%] wet weight basis			
		landfilling	incineration	composting	others
Kathmandu	2000	100.0			
Shanghai	1996	100.0			
Bangkok	1999	100.0			
India	1991	89.8		8.6	1.6
Osaka	1998	7.2	91.3		1.5
Japan	1995	11.5	76.2	0.1	12.2

3. Composting of model waste

The composting is an alternative technique, which is suitable especially to the disposal of the food waste. Batch composting experiments are carried out to know the amount of the global warming gas emission, etc. O*kara* (been curd lees) was selected as a model food waste, because the C/N ratio of okara is almost same as that of real food waste. The household digester, SANYO *Gomi-Nice* SNS-M15, was used as a composting apparatus. *Okara* was put into the apparatus everyday from t = 0 to 9 or 10 day.

The temperatures in the composted residues are presented along time in Fig.1. The temperature was lowered and the digestion of okara was completed after t=13 day. The conversions of *okara* and the

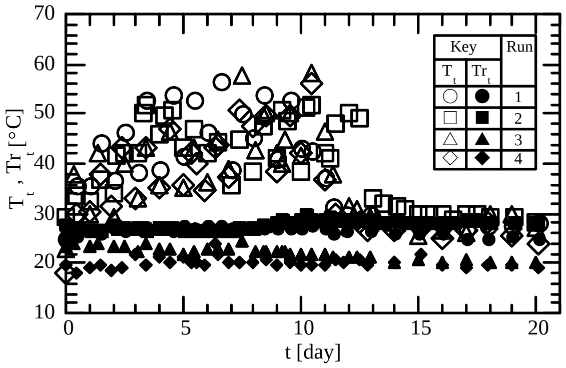
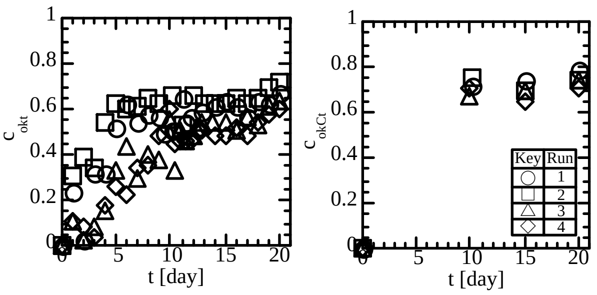


Fig. 1 Time courses of temperature in composted residue



(a) *okara* to gas (b) **C** in *okara* to gas

Fig.2 Time courses of conversions defined by Eqs. (1) and (2)

carbon in *okara* to gas components at composting time t, c_{okt} and c_{okCt}, were defined as follows:

$$c_{okt} = \frac{\sum_{t_k=0}^{t} m_{okDt_k} - \Delta M_{okDt}}{\sum_{t_k=0}^{t} m_{okDt_k}} \tag{1}$$

$$c_{okCt} = \frac{\sum_{t_k=0}^{t} m_{okCt_k} - \Delta M_{okCt}}{\sum_{t_k=0}^{t} m_{okCt_k}} \tag{2}$$

These are shown in Fig. 2 (a) and (b), respectively. c_{okt} was almost constant at 0.5~0.7 from t = 13 to 17 day in all runs. c_{okt} decreased after t = 18 by the decomposition of the wood tips attached to the digester. c_{okct} was 0.6 ~ 0.8 for all runs.

4. Disposal system to improve environment

The disposal system consisting of composting, incineration, and landfilling was synthesized and was calculated with the results presented above. The outline of the system is shown in Fig.3. MSW was separated into three streams each of which led to an appropriate unit disposal operation, composting, incineration, or landfilling. The contents in the model waste in this calculation are shown in Fig.4.

The conversion of the waste to the gas components in a disposal operation n was defined as

$$c_n = \frac{W_{1n} - R_n}{W_{1n}} \tag{3}$$

The material balance relations, therefore, gives

$$c_n = \sum_i c_{n,i} \cdot W_{1n} \cdot x_{W1n,i} \tag{4}$$

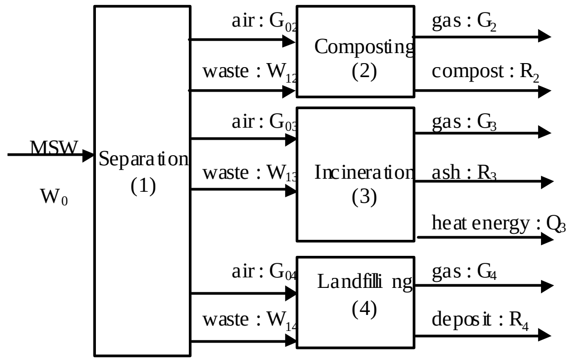


Fig. 3 Flow chart of disposal system supposed in this study

waste	components	chemicals	elements
MSW	food	cellulose	---- C, H, O
		lignin	---- C, H, O
		easily degradables	---- C, H, N, O
		ash	
		H_2O	---- H, O
	wood & paper	cellulose	---- C, H, O
		lignin	---- C, H, O
		ash	
	plastics	volatile solid	---- C, H, O
		ash	

Fig. 4 MSW contents supposed in this study

Table 4 Values used in the calculations

(a) Contents in 3 MSWs supposed in this study

Type	$x_{W0,Fd}$	$x_{W0,WP}$	$x_{W0,Pl}$	**model**
MSW-I	0.96	0.02	0.02	Kathmandu
MSW-II	0.80	0.10	0.10	Bangkok, Shanghai, India
MSW-III	0.50	0.35	0.15	Japan

(b) Values of $x_{i,j}$s

i \ j	cl	lg	ed	v	ash	H2O
Fd	0.072	0.004	0.116		0.008	0.800
WP	0.700	0.250			0.050	
Pl				0.950	0.050	

	C	H	N	O
cl	0.444	0.062		0.494
lg	0.730	0.070		0.200
ed	0.527	0.080	0.086	0.307
v	0.800	0.130		0.070

(c) Coefficients meaning conversions

composting (2)		incineration (3)		landfilling (4)			
$c_{2,Fd}$	0.6	$c_{3,C}$	1	$c_{4,cl}$	1	$c_{4,cl,CO2}$	0.4
$c_{2,WP}$	0.1	$c_{3,H}$	1	$c_{4,lg}$	0	$c_{4,cl,CH4}$	0.6
$c_{2,Pl}$	0	$c_{3,N}$	1	$c_{4,ed}$	1	$c_{4,lg,C}$	0
$c_{2,Fd,CO2}$	0.7	$c_{3,O}$	1	$c_{4,v}$	0	$c_{4,ed,CO2}$	1 ($x_{W14,H20} < 0.7$)
$c_{2,Fd,CH4}$	0	$c_{3,ash}$	0	$c_{4,ash}$	0		0.4 ($x_{W14,H20} \geq 0.7$)
$c_{2,WP,CO2}$	0.1	$c_{3,C,CO2}$	1			$c_{4,ed,CH4}$	0 ($x_{W14,H20} < 0.7$)
$c_{2,WP,CH4}$	0						0.6 ($x_{W14,H20} \geq 0.7$)
$c_{2,Pl,C}$	0					$c_{4,v,C}$	0

with the conversion of the respective component i. The carbon contents in the air was neglected and the conversions of the carbon in the waste to CO_2 and CH_4 were defined by

$$c_{n,j} = \frac{G_{n,j}}{W'_{1n} \cdot x'_{W1n,C}} \quad (j\text{=CO2, CH4}) \tag{5}$$

and similarly with the derivation of Eq.(4)

$$. \quad c_{n,j} = \sum_i c_{n,i,j} \cdot W_{1n} \cdot x_{W1n,i} \tag{6}$$

The degree of the separation, $\alpha_{i,n}$, was defined as

Table 5 Separation method supposed in this study
: alternative methods expressed in **bold letters**

No.	initial method	additional method		
		Food	Wood & Paper	Plastics
1	only landfilling	**compositng**	landfilling	landfilling
2		**compositng**	**compositng**	landfilling
3		**incineration**	**incineration**	landfilling
4		**incineration**	**incineration**	**incineration**
5	additional method of No. 3	**compositng**	incineration	landfilling
6	additional method of No. 4	**compositng**	incineration	incineration

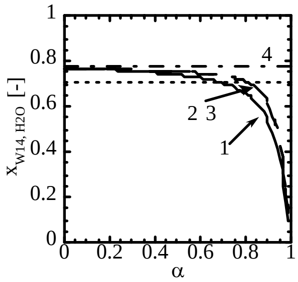
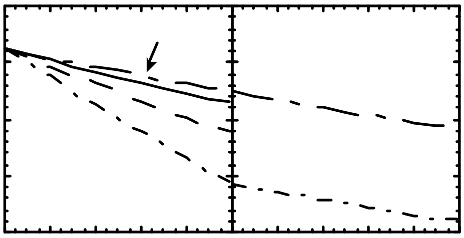
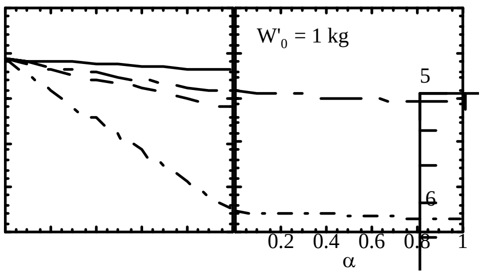


Fig. 5 Moisture content in the waste for landfilling



(a) MSW-I



(b) MSW-II

Fig. 6 Accumulation in disposal sites

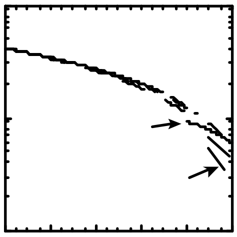
$$\alpha_{i,n} = \frac{W_{1n} \cdot x_{\mathrm{W}1n,i}}{W_0 \cdot x_{\mathrm{W}0,i}} \tag{7}$$

where n denotes an additional operation and i, a waste to be disposed.

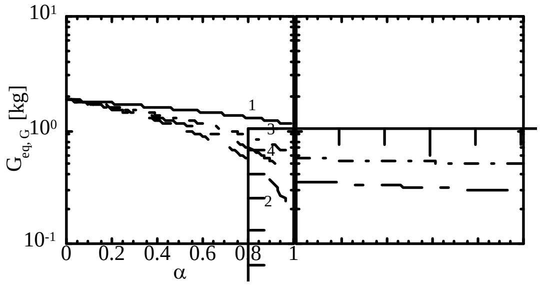
The principal calculation conditions, parameters, and specifications are listed on Tables 4 and 5. These values were fixed according to the situation of the MSW disposal in the developing countries and the experimental results mentioned above. The effects of the alternatives to the landfilling on the various factors representative of the environment were studied for the six methods given in Table 5.

An example of the moisture contents in the wastes to be landfilled are shown in Fig.5. Method 1 was the most effective to reduce the moisture content for all MSWs.

Figure 6 shows the dry mass of the waste to be landfilled, R'. R' could be lowered most remarkably by Method 4 for all MSWs. Whereas Method 1 could decrease R' for MSW-I, the method did not affect R' in the case of MSW-II.

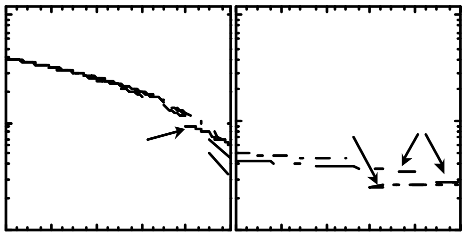


(a) MSW-I

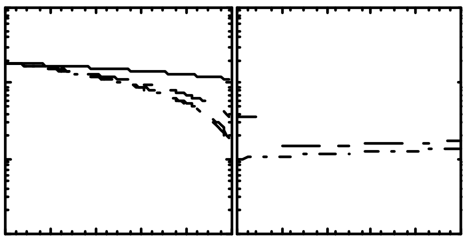


(b) MSW-II

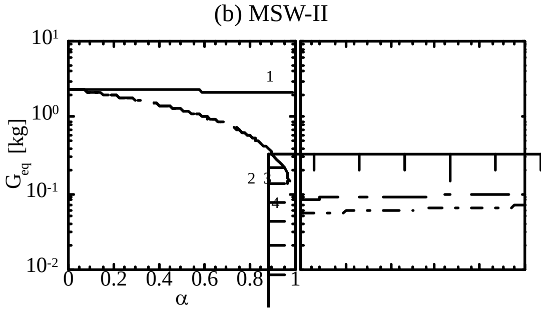
Fig. 7 CO_2-carbon equivalent of the global gas emissions



(a) MSW-I



(b) MSW-II



(c) MSW-III

Fig. 8 Emission of global warming gases including heat recovery

The CO_2-carbon equivalent to the emitted global warming gas, $G_{eq,G}$, is shown in Fig.7. $G_{eq,G}$ in Method 2 was lowest for all MSWs. The GWP of CH_4 was fixed at 21 in this calculation. In the case of MSW-I, $G_{eq,G}$ decreased stepwise at a certain α where the

Table 6 Effects on environmental improvement

	MSW-I					MSW-II				
	$x_{W4,H2O}$	R'	$G_{eq,G}$	Q_3	G_{eq}	$x_{W4,H2O}$	R'	$G_{eq,G}$	Q_3	G_{eq}
No. 1	◎	○	○	-	○	◎	△	△	-	△
No. 2	○	○	◎	-	◎	○	○	◎	-	○
No. 3	○	○	○	×	○	○	○	○	×	○
No. 4	×	◎	○	×	○	×	◎	○	◎	◎
No. 5	-	○	△	○	○	-	△	△	○	○
No. 6	-	○	△	◎	○	-	△	△	×	×

	MSW-III				
	$x_{W4,H2O}$	R'	$G_{eq,G}$	Q_3	G_{eq}
No. 1	◎	×	×	-	×
No. 2	○	○	◎	-	○
No. 3	○	○	○	○	○
No. 4	×	◎	○	◎	◎
No. 5	-	×	×	×	×
No. 6	-	×	×	×	×

landfill-site changed between anaerobic and aerobic(Fig.5). Method 1 for MSW-II was less effective than that for MSW-I. $G_{eq,G}$ from MSW-III was almost equivalent to that from MSW-II for all methods. Methods 1, 5 and 6 did not influence $G_{eq,G}$.

If the heat generated from the waste incineration could be utilized, the global warming gas emitted from the combustion of the fossil fuel could be decreased. Figure 8 shows the CO_2-carbon equivalent to the global warming gas in the case with the heat recovery from the incineration. G_{eq} were lowered by the heat recovery in the case of Methods 4 and 6 for MSW-II and of all methods for MSW-III. The heat recoveries reduced G_{eq} where α were higher than a certain value in the case of Methods 5 and 6 for MSW-I and of Method 5 for MSW-II.

Table 6 summarizes the whole results. The most effective alternative to improve the environment depend upon the composition of MSW. The composting was a good alternative for MSW-I. For MSW-II, the composting was less effective and the incineration was effective. While the composting of the food waste in MSW-III had little effect on the environmental improvement, the incineration was more effective.

5. Conclusion

The researches including the field activities made clear the actual conditions of MSW and the disposal of it in the developing countries. The gas emission from the composting of the food waste could be estimated from the experiments. The calculations with the above results demonstrated the feasibility of the MSW disposal system synthesized. In conclusion, this system was proposed for the MSW disposal in the developing countries to improve the environment.

Nomenclatures

c_n	: conversion of W_{1n} to gas by disposal n	[-]
$c_{n,i}$	: conversion of i to gas by disposal n	[-]
$c_{n,i,j}$	: conversion of i to j by disposal n (j = CO2, CH4)	[-]
$c_{n,j}$	: conversion of W_{1n} to j (j = CO2, CH4)	[-]
c_{okCt}	: conversion of **C** in *okara* to gas at time t	[-]
c_{okt}	: conversion of *okara* to gas at time t	[-]
G_{eq}	: CO_2-carbon equivalent including the effect of heat recovery	[kg]
$G_{eq,G}$	: CO_2-carbon equivalent of emitted gases	[kg]
G_n	: mass of gas emitted from disposal n	[kg]
m_{okCt}	: mass of **C** in *okara* thrown at time t	[kg]
m_{okDt}	: dry mass of *okara* thrown at time t	[kg]
Q_3	: heat of incineration	[kJ]
R_n	: mass of solid from disposal n	
R'	: dry mass of accumulation in disposal site (= $R'_3 + R'_4$)	[kg]
R'_n	: dry mass of R_n	[kg]
t	: composting time	[day]
t_k	: time when *okara* thrown	[day]
W_0	: mass of MSW before separation	[kg]
W_{1n}	: mass of waste for disposal n	[kg]
W'	: dry mass of W	
$x_{i,j}$	: mass fraction of j in i	[-]
x'	: mass fraction based on dry mass	[-]
$\alpha_{i,n}$	: defined by Eq. (7)	[-]
ΔM_{okCt}	: dry mass of accumulation of **C** in *okara* at time t	[kg]
ΔM_{okDt}	: dry mass of accumulation of *okara* at time t	[kg]

subscripts

0	: initial	1	: separation
2	: composting	3	: incineration
4	: landfilling	ash	: ash
C	: carbon	CH4	: methane
CO2	: carbon dioxide	cl	: celullose
ed	: easily degraded materials		
Fd	: food waste	H2O	: water
lg	: lignin	ok	: *okara*
Pl	: plastics waste	t	: time
v	: volatile solid	WP	: wood and paper waste

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