Improvement of the Process to Dispose of Municipal Solid Waste in the Developing Regions

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開発途上地域における都市廃棄物処理プロセスの改善

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まず, 開発途上地域の廃棄物に関する調査により, 厨芥が大半を占める廃棄物のほとんどを未処理のまま埋め立て処分しており, 処分場の不足, 種々の環境問題が深刻化していることを明らかにした。ついで, 埋め立て処分の前処理として, メタン発酵, コンポスト化, 及び焼却を導入したプロセスについて計算により検討した。埋め立て処分量, 総括的な温室効果気体の排出量は低減され, メタン発酵や焼却などから回収されるエネルギーにより本プロセスを稼動させられる結果を得た。

1, Introduction

Nowadays, it is a serious subject how to deal with waste and it trends to use waste for energy efficiently or recycle it in the earth scale.

In the developing regions, the amount of municipal solid waste (MSW) discharged is increasing tremendously due to the economic development, urbanization and population increase. Since most portion of the MSW is landfilled without any treatment in these regions, it becomes difficult to make new landfilling site and there are serious environmental problems around the existing site, such as soil pollution, subterranean water pollution, bad smell. Moreover, the methane, the strong green house effect gas (GHG) generated and is released into atmosphere. It is, therefore, necessary to introduce an alternative waste processing method, immediately.

To solve this problem, there are many efforts to apply various techniques to dispose of MSW, e.g., methane fermentation (anaerobic digestion), composting (aerobic digestion), incineration, and so on. However, almost all these studies deal with the performances of the respective techniques themselves. Although some studies of the synthesis and the effect on the environment of the whole process composed of these techniques in certain city[1),2)]are reported, there are quite few studies taking account of the composition of MSW[3),4)]and energy recover from MSW is quite few.

The purpose of this study is to develop the MSW disposal process consisting of methane fermentation, composting and incineration in addition to landfilling for the developing regions to improve both the regional and global environments.

2, Present conditions of MSW in developing regions

Amount and properties of MSW

The amounts of MSW generation per capita in the developing countries are now lower than advanced nation. They are expected to be going to catch up with or to exceed those in the advanced nations, because of remarkable economic growth, urbanization and increase in population.

Table 1 shows the compositions of MSW in several countries. In general, MSW's in the developing countries are roughly classified into three species: food waste; paper and wood; and plastic. The fractions of food waste in the developing regions are higher than those in the advanced nations. The water content of MSW is, thus, high since food waste contains large amount of water. On the other hand, the fractions of paper and wood in developing regions are lower.

Table 1 Composition of MSW in developing countries [5),6),7),8)]

	Food	Paper	Plastic	Model countries
MSWA	0.9	0.05	0.05	Nepal,Bangladesh
MSWB	0.8	0.1	0.1	Sri Lanka,India，Indonesia
MSWC	0.55	0.35	0.1	Malaysia(Kualan Lumpur)
MSWD	0.4	0.4	0.2	Japan,Singapore

MSW disposal methods

The shares of the MSW disposal methods developing countries are shown in **Table 2**. Whereas about 80 % of MSW is incinerated in Japan, most of the MSWis disposed of by landfilling, especially open dumping where there is no facility to prevent leaking leachate and/or to recover biogas and generate electricity. There are, thus, various environmental problems around the site. The shares of the composting and incineration are still low.

Table2 MSW disposal treatment in developing countries[9)] [%]

	Landfilling (sanitary)	Open dumping	Compost	Incineration	Other
Malaysia	30	50	10	5	5
China	30	50	10	2	8
India	15	60	10	5	10
Indonesia	10	60	15	2	13
Philippine	10	75	10	-	5
Sri Lanka	-	85	5	-	10

The energy balance and GHG emission about MSW

The energy consumption is increasing due to economic development and the raise of the standard of living in developing regions. Although Malaysia is exporting oil and natural gas, these fossil fuels may be exhausted with several decades. The electricity generation from waste, which is now starting to be operated, still contributes only small fraction in the primary energy supply.

The amount of GHG emission from various sources in Philippine is shown **Figure 1**. In developing regions, methane whose green house effect is intense is generated from landfilling site since most of the MSW is landfilled without recovery of biogas from the site. It is obvious from the figure that, although the amount of GHG emission from waste was almost constant, the fraction of that from waste increased, since the total amount of the emission decreased.

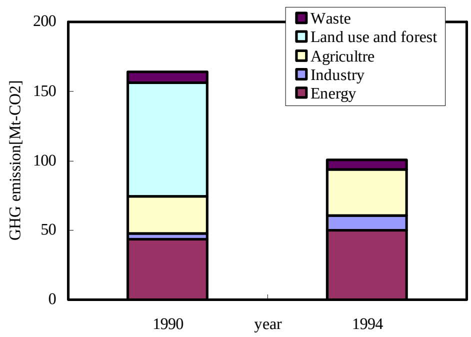

Fig.1 The amount of the GHG emission in Philippine [10),11)]

3. MSW treatment methods suitable for developing regions

Whereas it is easy to apply landfilling to the disposal in developing regions, this method cannot accommodate the considerably growing amount of MSW and the environmental problem by this methods are serious. By introducing other treatment of waste, it is important the composition and quantity of the waste carried into a landfilling site. Incineration is most widely used waste disposal way in Japan. It can reduce the amount of waste remarkably and the heat energy can be recovered in it. But it dose not fits better because calorie of MSW of the developing regions is low and low temperature in pit do damage to fire pit and occur hazardous gas such as dioxin. The conversion of waste into refused derived fuel (RDF) is another process to obtain energy. RDF is prepared by crushing and solidification of MSW after removal of non-combustibles. Although the heat value of RDF is high, the preparation of this requires much amount of energy[12]. There are two types of bioconversions appropriate for the food waste disposal: composting and methane fermentation. These are easy to be operated and can produce organic fertilizer. In the methane fermentation, offgas rich in methane can be recovered as an energy source as well. These are applicable to the disposal of MSW whose food waste content is high in the developing regions.

4 MSW disposal process

Outline of the process

Figure 2 shows the schematic diagram of the MSW disposal process. This process consists of the methane fermentation (1), composting A (2), composting B (3), and incineration (4) as pretreatments followed by the landfilling (5). The methane fermentation is dry methane fermentation where the solid concentration is high (20~40%). The composting A corresponds to the primary fermentation and the composting B, to the secondary one in this process.

High speed composting which decomposes easy biodegradable substrates is achieved in the composting A. In the composting B, windrow composting is conducted to maturate the solid residues from the methane fermentation or composting A into compost product. The facilities of the methane fermentation and composting A are relatively small to middle scale and can be located near the suburban-area. The composting B, incineration, and landfilling require large scale of facilities and should be isolated from the city area.

The MSW after recovery of valuable resources, such as metal, glass, and a bulky garbage, F_0, is fractionated into several MSW streams, F_{01}, F_{02}, F_{03}, F_{04}, F_{05}, before entering into the process. These fractionated streams are provided to the respective proper treatment operations in the process.

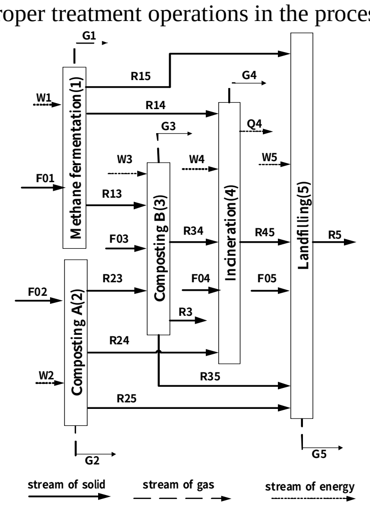

Fig.2 Block flowchart of MSW disposal process

Calculation

The process was simulated as mentioned below. The quantitative details of basic equations, assumptions, definitions, and so on, are omitted here.

(1) original MSW

Table 3 shows the composition of the MSW. The original MSW, F0, contained food waste (Fd), wood and paper (WP), and plastic (Pl). These species of MSW consisted of cellulose (Cel), lignin (Lg), biodegradable substance (BD), non biodegradable substance (NB), ash (Ash), and water (H2O).

Table 3 Composition of MSW

	waste component (*i*)	chemical (*j*)	element, *m*
MSW	Food (Fd)	Cel	… C, H, O
		Lg	… C, H, O
		BD	… C, H, N, O
		Ash	… Ash
		H_2O	… H, O
	Wood & Paper (WP)	Cel	… C, H, O
		Lg	… C, H, O
		Ash	… Ash
		H_2O	… H, O
	Plastic (Pl)	NB	… C, H, O
		Ash	… Ash

(2) methane fermentation

BD and a portion of Cel were decomposed. Generated gas contained methane (CH4), carbon dioxide (CO2), and ammonia (NH3). These gases were recovered and combusted to be converted into the electricity.

(3) composting A and B

In composting A and B, BD and a portion of Cel were decomposed. WP contained in R2,in disturbed the decompositions of BD and Cel. Generated gas contained CO2, NH3, and Nitrous oxide (N2O). A part of composting residue was recovered as an organic fertilizer.

(4) incineration

$R_{4,\mathrm{in}}$ was incinerated with the condition of perfect combustion. Generated gas contained only CO2. Heat recovery was calculated from the ratio of mass fractions of water and ash. It depended upon the heat value of $R_{4,\mathrm{in}}$ whether the electricity power could be generated or not.

(5) landfilling

An aerobic decomposition of BD was dominant with lower moisture content in $R_{5,\mathrm{in}}$. The higher moisture content in $R_{5,\mathrm{in}}$ made an anaerobic decomposition of BD controllin. Cel was decomposed anaerobically under all condition of the moisture content in $R_{5,\mathrm{in}}$. Generated gas contains CO2, CH4, and NH3.

(6) principal conditions

The compositions of respective MSW species are summarized in **Table 1**. The generation rate of the original MSW, F_0, was 1 t/d. F_0 was comprised of the food waste (Fd), wood and paper (WP), and plastic (Pl). Under the above conditions, landfilling rate of the solid residue, R_5,in, water content in R_5,in, and ultimate accumulation rate in the landfill site, R_5, were estimated. The work required for each treatment operation, Wi, and recovered energy from biogas combustion, Q_1, recovered equivalent energy of organic fertilizer from composting, Q_3, and recovered energy from incineration,Q_4, were calculated. CO2, CH4, and N2O were considered as GHG's.

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Results and Discussion

Figures 3 shows the relation between the degradations of MSW components and emission gases in the case of MSW A landfilled directly with no treatment and **Fig.4** shows that in the case of MSW C. The ratio of CO2 emission relative to CH4 was different between the cases of MSW A and C, since the food waste content, i.e., the moisture content of MSW A was higher and the anaerobic decomposition of BD was occurred. High ratio of CH4 was generated because of anaerobic decomposition of BD. Most of the gas emission from decomposed BD was CO2, because aerobic decomposition of BD was carried out. Most of CH4 was generated from Cel. The amount of Cel influenced on the amount of CH4 if the moisture content in R_5,in was lower.

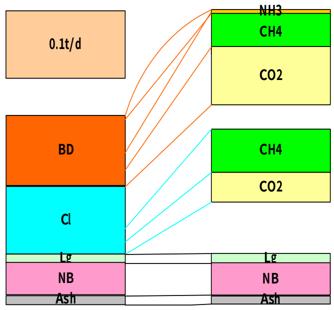

Fig.3 Composition variance of MSW A (Fd,WP,Pl) and gas emission to landfilling

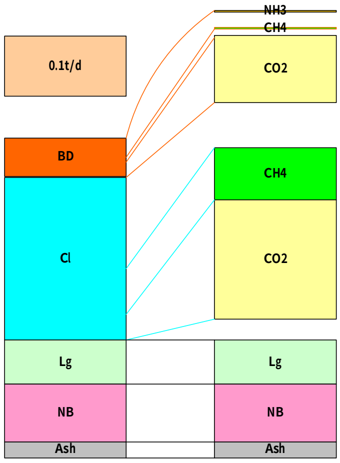

Fig.4 Composition variance of MSW C (Fd,WP,Pl) and gas emission to landfilling

Figure 5 shows the MSW reduction, amount of gas emission, requirement and recovery of energy in the case of MSW B where the food waste was treated in the composting A ($R_{2,\mathrm{in}}$=$F_{0,2}$, $x_{F0,2,\mathrm{Fd}}$=1), the residue from the composting A and the wood and paper and plastic wastes were provided into the incineration ($R_{4,\mathrm{in}}$=$R_{2,4}$+$F_{0,4}$, $x_{F0,4,\mathrm{WP}}$=0.5, $x_{F0,4,\mathrm{Pl}}$=0.5), and the residue from the incineration was landfilled ($R_{5,\mathrm{in}}$=$F_{2,5}$) (abbreviated to $R_{2,4}$(Fd)-$R_{0,4}$(WP&Pl)), and **Fig.6** shows those where the food and wood and paper wastes, to the composting A (R_2,in=$F_{0,2}$, $x_{F0,2,Fd}$=0.888, $x_{F0,2,WP}$=0.111), the residue from the composting A and the plastic wastes, to the incineration (R_4,in=$R_{2,4}$+$F_{0,4}$, $x_{F0,4,\mathrm{Pl}}$=1), and the residue from the incineration was landfilled ($R_{5,\mathrm{in}}$=$F_{2,5}$) (abbreviated to $R_{2,4}$(Fd&WP)-$R_{0,4}$(Pl)). The energy recovery in $R_{2,4}$(Fd)-$R_{0,4}$(WP&Pl) were larger than that in $R_{2,4}$(Fd&WP)-$R_{0,4}$(Pl). The power value of $R_{4,\mathrm{in}}$ in $R_{2,4}$(Fd&WP)-$R_{0,4}$(Pl) was too low to obtain the energy in electricity form, as $R_{2,4}$ was larger than that in $R_{2,4}$(Fd)-$R_{0,4}$(WP&Pl) despite of the same moisture content specified by the condition of the composting A. $R_{2,4}$ in $R_{2,4}$(Fd&WP)-$R_{0,4}$(Pl) was enlarged also since WP disturbed the decomposition in the composting A.

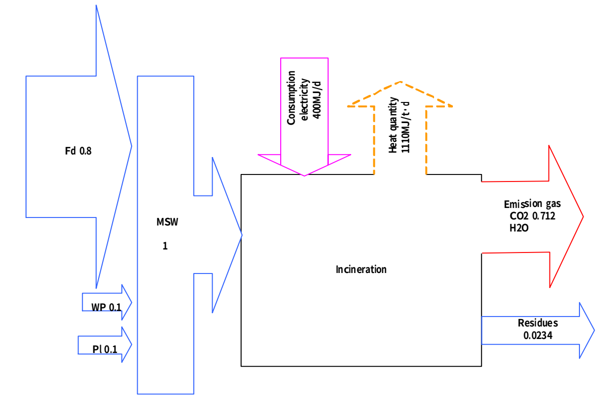

Fig.5 Conversion of R_{24}(Fd)＋F_{04}(WP,Pl) and consumption and recover energy at incineration [t/d]

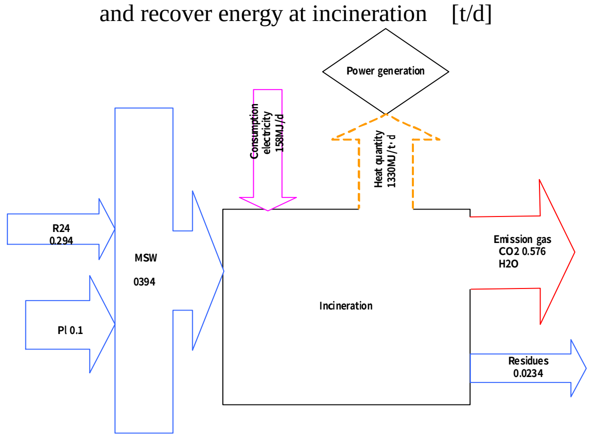

Fig.6 Conversion of R_{24}(Fd,WP)＋F_{04}(Pl) and consumption and recover energy at incineration [t/d]

Figure 7 shows the accumulation rates of the dry residue, the water in landfill site, and the total emission rates of GHG where MSW B were disposed of by several typical processes. In developing regions, most of the MSW was directly landfilled with no treatment as mentioned above (Lf,w,p in the figure). The emission of GHG and the water accumulation in the site were highest in Lf,w,p. The installation of the incineration in the process lowered the accumulation rates of the dry residue and the water in the landfill site (denoted by I in the figure) were favorably lowered. The emission of GHG was reduced by the methane fermentation (M in the figure). The emission of GHG was lowest where the food, wood, and paper wastes were disposed by the methane fermentation followed by the composting B to be organic fertilizer, and the plastic waste was simply landfilled (Mf,wCB-Lp). The consumptions of energies for the respective operations in the process are presented in Fig.8. The process containing only the landfilling required the lowest energy. The energy consumption was highest in the process where all of the original waste were incinerated and the residue of this was landfilled (If,w,p). The methane fermentation and incineration used relatively high energy. **Figure 9** gives the recovery of energy from the waste in the process. The large amounts of energies could be recovered by the methane fermentation and incineration. Relative to these operations, the energy recovery from the fertilizer product from composting B (CAB and CB) was low. These total consumption and recovery of energy in the process are compared in **Figure 10**. Although the methane fermentation and incineration consumed large amount of energy, these operations could also recover usable energy much more than consumed. The combination of the methane fermentation and incineration was profitable in terms of energy. There are various problems around MSW in the developing regions as described before. The most pressing problem at present is the difficulty in opening up new sites of landfilling with terrible increase of the MSW. The amount of MSW to be landfilled should be, therefore, reduced immediately. Although the incineration has desirable performance as for the reduction of MSW, it cannot recover the enough energy by itself without any pretreatment in the process and would be hard to be applicable to the MSW disposal in the developing regions. With respect to the energy recovery, the methane fermentation is excellent. Consequently, the incineration is suggested to be employed with any pretreatment, especially the methane fermentation, for the MSW disposal process in the developing regions. The suggested process can also diminish the emission of GHG derived from MSW into the atmosphere.

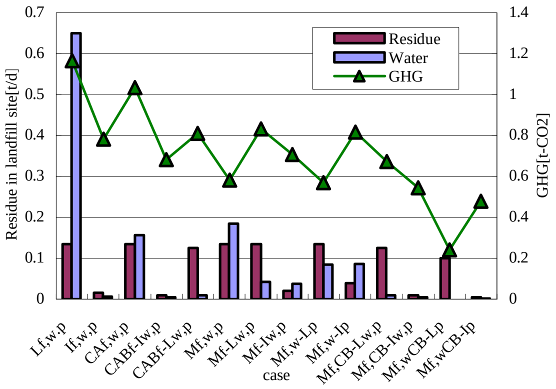

Fig.7 The amount of residues and water in landfill site and total GHG

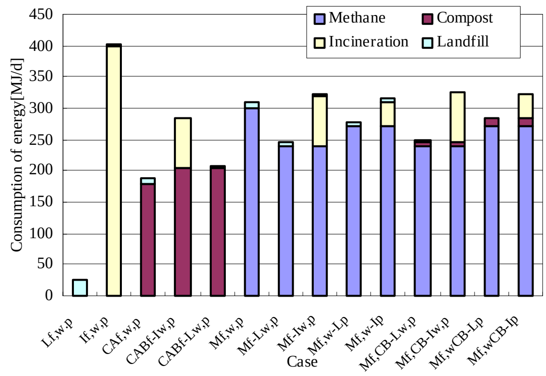

Fig.8 Consumption energy to dispose MSW

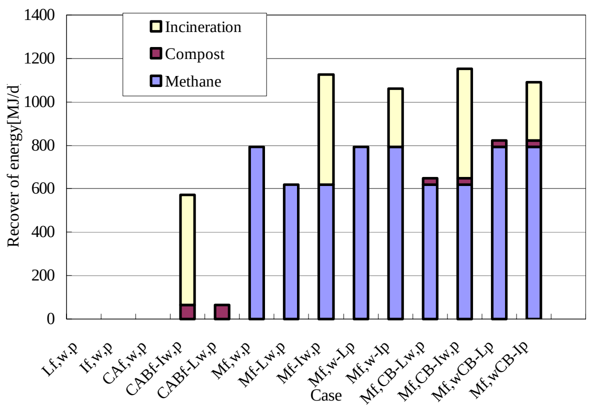

Fig.9 Recover energy to dispose MSW

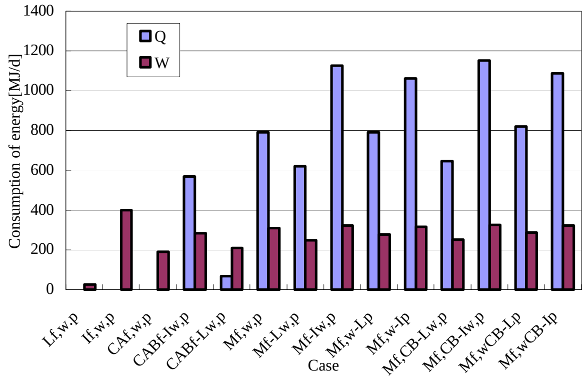

Fig.10 Consumption and recovered energy

4, Conclusion

New MSW disposal process in developing regions was proposed. It reduced residues in landfill site and GHG in addition to the increase energy recover.

Nomenclature

CA	[-]:	composting A
CB	[-]:	composting B
F	[t/d]:	feed waste
I	[-]:	incineration
M	[-]:	methane fermentation
G	[t/d]:	emission gas
Q	[MJ/d]:	recovered energy
R	[t/d]:	residues
W	[MJ/d]:	consumption energy

<Subscripts>

0	initial number
1~5	disposal number
f	disposal food
in	input
p	disposal plastic
w	disposal wood and paper

Reference

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