Collection and recycling of paper and plastic for municipal solid waste management in developing countries

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1. Introduction

In many developing countries, most of the municipal solid waste (MSW) is landfilled. However in recent years, the advance of urbanization and improvement in income level have created a serious problem; the shortage of landfill sites. It has been accelerated by a marked increase in plastic waste. Therefore, it is necessary to introduce alternative MSW disposal method that will replace landfilling method.

In previous study, MSW management system[1) including landfilling, incineration, and composting is studied to investigate environmental influences such as Green House effect Gas (GHG), energy consumption, and amount of solid residue that remain at landfill sites. However, the study considering recycling has not been carried out.

The purpose of this research is to examine effects of recycling and to propose MSW management system that will reduce the unwilling environmental burdens. So a MSW management system that comprised by incineration, recycling, and landfilling was simulated to examine its effects on the amount of solid residue, GHG emission, and energy consumption.

2. MSW management system

2.1 Outline of the system

Figure 1 shows the MSW management system. This is comprised five processes; separation (1), incineration (2), landfilling (3), paper recycling (4), and plastic recycling (5). Collected MSW is separated at separation process then paper and plastic for recycling are transferred to each recycling process. Remaining waste is incinerated or landfilled. Wi [MJ/day] shows energy flow that is needed for each process. Gi [ton/day] shows GHG flow from each process. R23 [ton/day] shows solid residue flow from incineration process, and then it is landfilled. R3 [ton/day] shows solid residue flow remaining at landfill sites.

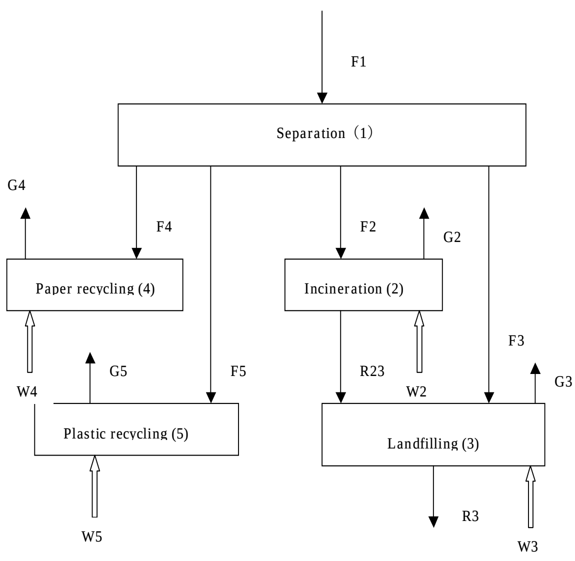

Figure1 MSW management system

2.2 Assumption

(1) General assumption

F1 contains only three components ; food (Fd), paper (Pa), and plastic (Pl). Recycling is applied to Pa and Pl. Calorific value of each component is Fd:2.4, Pa:17, Pl:33 (MJ/kg). These waste consist of cellulose (Cl), lignin (Lg), easy biodegradable substances (ED), non-biodegradable substances (ND), ash (As), and water (Wt). For GHG, only CO_2 and CH_4 are considered, and their warming index is 1 for CO_2 and 21 for CH_4.[3)] Required energy for each disposal operation is acquired by consuming fossil fuel and so CO_2 emission from energy consumption in each disposal process is added to total GHG emission.

(2)Assumption in incineration operation

Perfect combustion of the combustibles (Cl, Lg, ED, andND)is carried out and emitted GHG is only CO_2. As and Wt do not change.

(3) Assumption in landfilling operation

Anaerobic decomposition of Cl and ED is carried out. Generated GHG are CO_2 and CH_4. Carbon conversion rates in landfilling operation into CO_2 is 0.4, CH_4 is 0.6. Lg, ND, As, and Wt do not change.

(4) Assumption in recycling operation

Paper is reprocessed into pulp and plastic is reprocessed into plastic pellet. No GHG is generated in recycling processes.

2.3 Calculation

Waste flow input F1 is 7000[ton/day]. Constituent proportion of F1 is Fd : Pa : Pl =0.6 : 0.25 : 0.15. These conditions are determined with considering typical developing countries. Composition of each waste ingredient used for calculation are shown in **Table 2.1** . Compositions of Fd was based on Okara used as model food waste. Compositions of Pa and Pl were estimated with literature and reported experiments. The mass fraction of C, N, H, and O in Cl, Lg, ED, and ND are shown in **Table 2.2**. It was estimated with the literature. Energy consumption of each process were landfilling : 0.001 , incineration : 0.2 , paper recycling : 0.56 , plastic recycling : 17.4 [MJ/kg][4] . GHG emission from energy consumption in each process was accounted for total GHG.

The specifications of MSW separation are shown at **Table2.3**. Total amount of solid residue in landfill sites, energy consumption, GHG emission, and calorific value of MSW were calculated when recycling rate (Re) was 0%, 20%, 40%, 60%, 80%, 100%.

Table 2.1 Mass fractions of substances in waste components

	Cl	Lg	ED	ND	As	Wt
Fd	0.07	0.004	0.118	0	0.008	0.8
Pa	0.07	0.25	0	0	0.05	0
Pl	0	0	0	0.95	0.05	0

Table 2.2 Mass fractions of elements in substances

	C	H	N	O
Cl	0.44	0.06	0	0.5
Lg	0.73	0.07	0	0.2
ED	0.53	0.08	0.086	0.3
ND	0.8	0.13	0	0

Table 2.3 Specifications of separation

Case	Fd	Pa	Pl
1	L	R,L	R,L
2	L	R,I	R,I
3	I	R,L	R,L
4	I	R,I	R,I

(L :landfilling I : incineration R : recycling)

3.4 Results and discussion

In the cases that adopt incineration operation (case2, 3, and 4), MSW need to have enough calorific value for its combustion. The lower limit of the calorific value is 3.6MJ/kg. From **Table 3.4**, case3 and case4 (at Re100%) did not achieve this limit, so additional fuel was needed. Considering additional fuel, it was important to take its energy consumption and GHG emission into account.

Current condition was the bar graph at recycling rate 0% in case1 (all MSW was landfilled). **Figure 2** shows the amount of solid residue in each case. As paper and plastic recycling is increased, the amount of solid residue decreases. Comparing case3 with case4 , it is clear that incinerating plastic which does not decompose in landfill site is efficient. **Figure 3** shows energy consumption in each case. Current landfilling is the most economical method. When recycling is adopted, energy consumption is largely increased. Because of additional fuel in order to burn food waste, energy consumption is very high in case3. **Figure 4** shows GHG emission in each case. GHG emission of current landfilling is worst because CH_4 generated from landfill sites is very strong GHG. GHG emission decrease by adopting recycling.

3. Conclusion

It is figured out that paper and plastic recycling in developing countries is efficient for the problem of landfilling sites and decreasing GHG emission, though energy consumption is higher than landfilling. The system that combines incineration and recycling is suggestible as alternative MSW disposing method in developing countries.

4. Nomenclature

MSW; municipal solid waste, GHG; green house effect gas, CO_2; carbon dioxide, CH_4; methane, Fd; food waste, Pa; paper, Pl; plastic, Cl; cellulose, Lg: lignin, ED; easy biodegradable substances, ND: non biodegradable substances , As: ash, Wt: water, C: carbon atom, H: hydrogen atom, N: nitrogen atom, O: oxygen atom, F; waste flow [ton/day], G; GHG flow [ton/day], W; energy flow [MJ/MSW1kg], R; solid residue flow [ton/day]

5. References

1) Ayako Shimizu, Improvement of solid waste management system in developing countries,2002
2) 山谷修作、廃棄物とリサイクルの公共政策、中央経済社（2000）pp207
3) 霞ヶ関地球温暖化問題研究会編訳；IPCC 地球温暖化レポート、中央法規出版（1999）
4) 環境庁企画調整局環境研究技術課，ライフサイクルアセスメントの実践、化学工業日報社（1996）pp56

Table 2.4 Calorific values of MSW in each case

Case	Re0%	Re20%	Re40%	Re60%	Re80%	Re100%
2	23	23	23	23	23	23
3	2.4	2.4	2.4	2.4	2.4	2.4
4	11	9.5	8.3	6.7	4.8	2.4

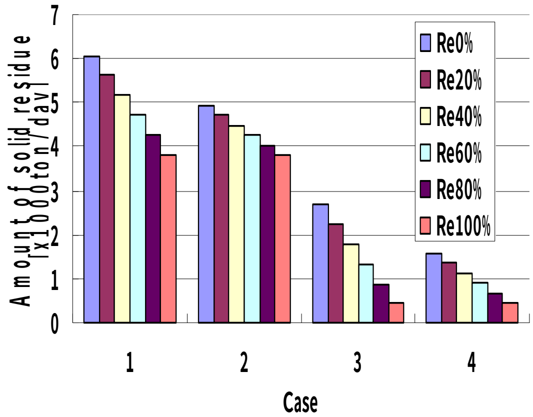

Figure2 Comparison of amount of solid residue in each case

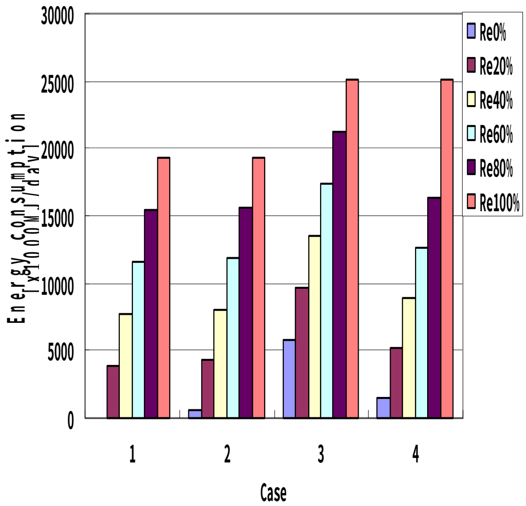

Figure3 Comparison of energy consumption in each case

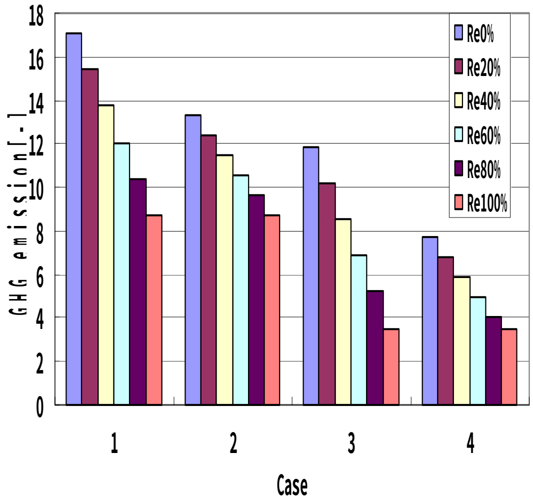

Figure4 Comparison of GHG emission in each case