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Use of Plastic Wastes as a Substitution Coal for the Optimization of Carbon Dioxide Reduction

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The most important problem surrounding plastic wastes recycling entails the optimization of carbon dioxide reduction. The energy and material industries, such as electric power generation, steel, and cement, use coal as fuel at the present time. A candidate formation of systems of networks, incorporating the recycling of plastic wastes in individual manufacturing processes, will make a decrease in emissions realization. Substitution coal with plastic wastes and evaluating the effects there of waste were estimated in three specific categories: 1) electric power generation (use in combination with coal), 2) the steel industry (combining with blast furnace materials and coke), and 3) the cement industry (as fuel). The energy value of plastic wastes after the dechlorination treatment is 9,774 kcal/kg. This value is higher than that of coals used in the electric power generation (6,200 kcal/kg), steel (6,900 kcal/kg) and cement (6,200 kcal/kg) industries. The ratios maximizing carbon dioxide reduction by utilizing the plastic wastes as a substitution coal reached 10.0% in electric power generation, 4.7% in the steel industry, and 28.8% in the cement industry. These key industries are dotted throughout Japan. Although all of Japan is not fully covered by constructing a 50km radius around these plans, a 100km radius will sufficiently do so. Therefore, a local circulation type recycling system can be built by using these key industry plants, because the transportation within 100km radius is economic rationality.

Key words: Recycling plastic wastes, Dechlorination of plastic wastes, Substitution coal, Utilizing of key industries,

1. INTRODUCTION

There are 10 million tons of plastic wastes in Japan. 47% of the waste is incinerated or sent to landfills. The remaining 53% is utilized via recycling, conversion into oil and gas, reduction in blast furnaces, incineration with power generators, and energy recovery [1]. However, incineration with power generation and energy recovery methods are considered unreasonable because these systems are inefficient.

Most mixed plastics are burned or landfilled. Recently, material industries, especially integrated steelworks, have established advanced plastic waste recycling processes. These processes include blast furnace feeding, chemical converting, oil recovery and gas recovery. Blast furnace feeding, which uses plastic wastes instead of coke, was introduced in the mid-1990's by Kawasaki and Fukuyama (JEF) in Japan [2], and DSD in Germany [3].

The most important problem surrounding plastic wastes recycling entails the optimization of carbon dioxide reduction. The energy and material industries, such as power generation, steel, cement, and paper-pulp, use coal as fuel at this present time. Therefore, forming a network system, i.e. incorporating the recycling of plastic wastes in each manufacturing process, will make a decrease in emissions a realization. The energy value of plastic wastes after the dechlorination treatment is 9,774 kcal/kg. This value is higher than that of the coal used in the industries mentioned in above. Therefore, use of plastic waste as a substitution coal is very effective in optimizing carbon dioxide reduction.

Dechlorination is the most important technology for recycling mixed polymer scrap. In dry processes, such as manual operation, it is difficult to fully remove poly(vinyl chloride) (PVC) from polymer scrap. To expand plastic waste recycling to some industries, development of dechlorination in concentrated alkali solutions is needed because of easy chemical and thermal recoveries [4-8].

The purpose of this study is to investigate two primary points/concepts.

- The effective use of plastic wastes for optimization of carbon dioxide reduction.

Table 1 Composition of mixed waste plastics. (A city: dry wt%)

	bottle	pack cup tray	wrap film sheet	handbag	bag with shaft	general merchandises household appliance	others	total	after separation
PE	5.20	1.35	0.41	13.12	4.07	-	13.84	37.99	48.16
PP	0.75	3.09	-	-	4.07	-	-	7.91	10.03
PS	0.68	11.71	-	-	4.07	-	-	16.46	20.37
PVC	1.29	0.45	1.55	-	0.12	2.11	1.38	6.90	8.75
PET	8.99	0.63	-	-	-	-	-	9.62	12.20
others	3.48	0.00	-	-	-	9.84	7.77	21.09	0.00
total	20.39	17.23	1.96	13.12	12.33	11.95	22.99	99.97	100.00

- Recycling plastic waste in local circulation.

Moreover, this research is further divided to focus on the following.

(1) The discharge form of plastic wastes.
(2) Trial calculations of energy capacities of plastic wastes.
(3) The amounts of coal utilized in electric power generation, steel, and cement industries
(4) The locations of key industries in Japan.

2. RESULTS and DISCUSSIONS

2.1 Composition of plastic wastes and tolerance levels for chlorine content in some plants

Table 1 shows the compositions of mixed plastic waste obtained from the household waste of a certain city. The main plastic wastes include extend bottles, packaging, cups, trays, wrapping film, sheets, bags, general merchandise, and household appliances; which consist of poly(ethylene) (PE), poly(propylene) (PP), poly(styrene) (PS), poly(ethylene terephthalate) (PET), and PVC. The mixture of PVC poses a large problem in plastic recycling due to the chlorine involved. Since plastic waste contains 9% of PVC, this correlates 45,000 ppm of chlorine in the waste. The high content of chlorine makes the utilization of mixed plastic wastes be impossible in several key industries.

Table 2 Tolerance level for chlorine in the feedstock recycling

process	tolerance level (ppm)
Visbreaking	2,000
Reduction in blast furnace	3,000
Hydrogenation	
in liquid phase	6,000
in gas phase	50
Steam-cracking	5
Catalytic cracking	50
Coking plant	20
Pyrolysis	60,000

Table 2 gives the chlorine tolerance level for the feedstock stream of a plastic waste recycling process [3]. Pyrolysis, which contains the highest tolerance level, is operable until 60,000 ppm. On the other hand, visbreaking, reduction in a blast

Table 3 Element components of mixed plastic wastes and dechrolinated plastics

	H/C	Cl/C	O/C	C	H	Cl	O
				wt%			
PE	2.00	0.00	0.00	85.71	14.29	0.00	0.00
PP	2.00	0.00	0.00	85.71	14.29	0.00	0.00
PS	2.67	0.00	0.00	92.31	7.69	0.00	0.00
PVC	1.00	0.50	0.00	38.40	4.80	57.0	0.00
PET	0.80	0.00	0.40	62.50	4.17	0.00	33.33
waste mixed plastics	1.57	0.03	0.04	79.22	10.37	5.94	4.46
dechlorinated plastics	1.59	0.00	0.04	84.07	11.17	0.00	4.75

Table 4 Energy capacity of mixed waste plastics

	energy capacity (kcal/kg)	ratio (wt%)	after dechlorination (wt%)
PE	11,000	26.76	28.50
PP	10,500	25.55	27.22
PS	9,800	23.84	25.39
PET	5,500	13.38	14.25
PVC	4,300	10.46	0
Dechlorinated PVC	11,000	0	4.63
MWP	9,148 (kcal/kg)		9,774 (kcal/kg)

furnace, and hydrogenation in liquid phase can only operate until the thousands ppm range, which is much lower than 45,000 ppm. In some cracking plants, such as steam-cracking and catalytic plant, and coking plants, the tolerance levels are even lower. Therefore, dechlorination treatment is a necessary step in recycling, particularly, in regards to the feedstock.

Currently, many dechlorination treatment systems have been developed as either dry or wet process. In order to achieve higher the recycling ratio, it is necessary to use the dechlorinated plastic wastes. Table 3 displays the components of plastic wastes, by element. The chlorine content is approximately 60,000 ppm before the dechlorination treatment. If the dechlorination proceeds to completion, the carbon and hydrogen concentrations increase. This means that using plastic wastes is widely applicable to increase energy capacity.

2.2 Calculation of the energy capacity of plastic wastes

Tables 3 and 4 show the element ratio and the energy capacity change before and after the dechlorination treatment. The dechlorination treatment does not affect the polyolefin plastics, except for PVC. It increases from 9,100 to

Table 5 The amount of waste plastics and energy capacity

	The amount of waste (million tons)	Energy capacity (kcal)
total used	10.16	9.34×10^{13}
total non-used	4.78	4.38×10^{13}
landfilled	2.85	2.61×10^{13}
incinerationed	1.93	1.77×10^{13}

ca.9,800 kcal/kg, because the carbon and

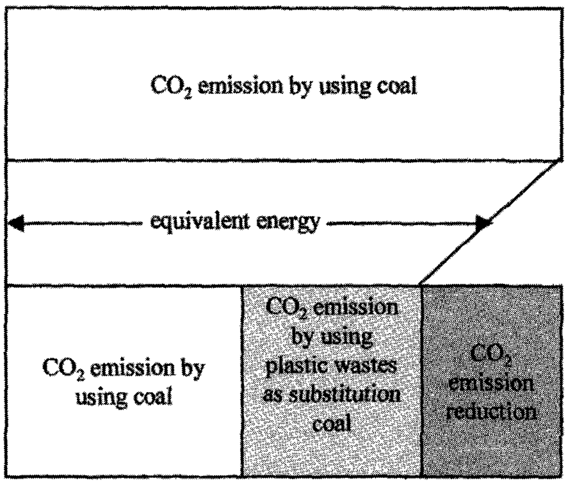

Figure 1 Definition for the carbon dioxide reduction

hydrogen content increases with the decreasing chlorine content. The energy capacity of the unused plastic wastes after the dechlorination treatment becomes 9.34×10^{13} kcal. Thus, the total energy capacity, for both reused and non-used plastics, reaches 4.38×10^{13}, kcal in case of total waste (see Table 5). These values were used as a basis for future calculations.

2.3 Definition for carbon dioxide reduction

The definition for carbon dioxide reduction is show in Figure 1. There is a beneficial impact on energy when using plastic wastes as a substitute because the energy capacity of plastic wastes are higher than that of coal. This also yields a positive impact on carbon dioxide emissions. The difference between using coal only and using plastic wastes as a substitution coal is the reduction in carbon dioxide emissions.

2.4 Calculation of carbon dioxide emissions in the key industries

The energy capacity of coal used in electric power generation is about 6,200 kcal/kg, and approximately 43.34 million tons of coal is consumed. The energy capacity is lower than that of plastic wastes after dechlorination. The difference is approximately 3,000 kcal/kg. And, the total energy for power generation utilizing coal reaches 2.69×10^{14} kcal. According to these calculations, carbon dioxide emission reaches 119 million tons.

Table 6 displays the reduction ratio of carbon dioxide emissions in electric power generation. For example, the use of increasing plastic wastes produces a carbon dioxide emission reduction ratio 1.9% in incineration. In landfilling plastic wastes, a 2.8% reduction ratio is produced. Thus, the reduction ratio is 4.7% for plastic wastes not used as a substitution coal. So, if the total plastic wastes forwarded to electric power generation, the amount of carbon dioxide emissions would be 11.9 million tons. This industry would then contribute to a 10.0% decrease in carbon dioxide

Table 6 Reduction ratio of carbon dioxide in power generation industry using plastic wastes

	use of waste plastics	(ratio of use)	coal consumption	(ratio)	CO_2 reduction	(ratio)
	million tons	(%)	million tons	(%)	million tons	(%)
without use	0	0.0	43.34	100.0		0.0
total used	10.16	100.0	34.74	80.2	11.93	10.0
total non-used	4.78	47.0	24.16	55.7	5.61	4.7
incineration	1.93	19.0	22.71	52.4	2.27	1.9
landfill	2.85	28.0	32.52	75.0	3.35	2.8

Table 7 Reduction ratio of carbon dioxide in steel industry using plastic wastes

	use of waste plastics	(ratio of use)	coal consumption	(ratio)	CO_2 reduction	(ratio)
	million tons	(%)	million tons	(%)	million tons	(%)
without use	0	0.0	86.01	100.0		0.0
total used	10.16	100.0	85.34	99.2	12.68	4.7
total non-use	4.78	48.0	55.63	64.7	5.97	2.2
incineration	1.93	19.0	48.19	56.0	2.41	0.8
landfill	2.85	28.0	69.15	80.4	3.55	1.3

Table 8 Reduction ratio of carbon dioxide in cement industry using plastic wastes

	use of waste plastics	(ratio of use)	coal consumption	(ratio)	CO_2 reduction	(ratio)
	million tons	(%)	million tons	(%)	million tons	(%)
without use	0	0.0	26.71	100.0		0.0
total used	10.16	100.0	0	0	7.69	28.8
total non-use	4.78	48.0	2.65	9.9	7.28	27.3
incineration	1.93	19.0	1.07	4.0	2.94	11.0
landfill	2.85	28.0	1.58	5.9	4.34	16.2

emissions.

Calculation results for the steel and cement industries are shown in Tables 7 and 8. In these cases, increasing the use of plastic wastes produces a reduction ratios of carbon dioxide emission of 0.8% (steel) and 11.0% (cement), in incineration. In landfilling plastic wastes, a 1.3% (steel) and 16.2% (cement) reduction ratio is produced. Thus, the reduction ratios would reach 2.2% (steel) and 27.3% (cement) for non-used plastic wastes as a substitution coal. If the total amount of plastic wastes are forwarded to electric power generation, the amount of carbon dioxide emissions would be 12.7 (steel) and 7.7 million tons (cement). These industries would then contribute to a 4.7 (steel) and 28.8% (cement) decreases in carbon dioxide emissions.

2.5 Local circulation recycling systems using key industry plants in Japan

Japan is dotted with many key industrial plants. A 50km radius surrounding these plants is not large enough to encompass all of Japan; but a 100km radius covers Japan in its entirety, as shown in Figure 2. Therefore, a local circulation type of recycling system can be built using these key industrial plants.

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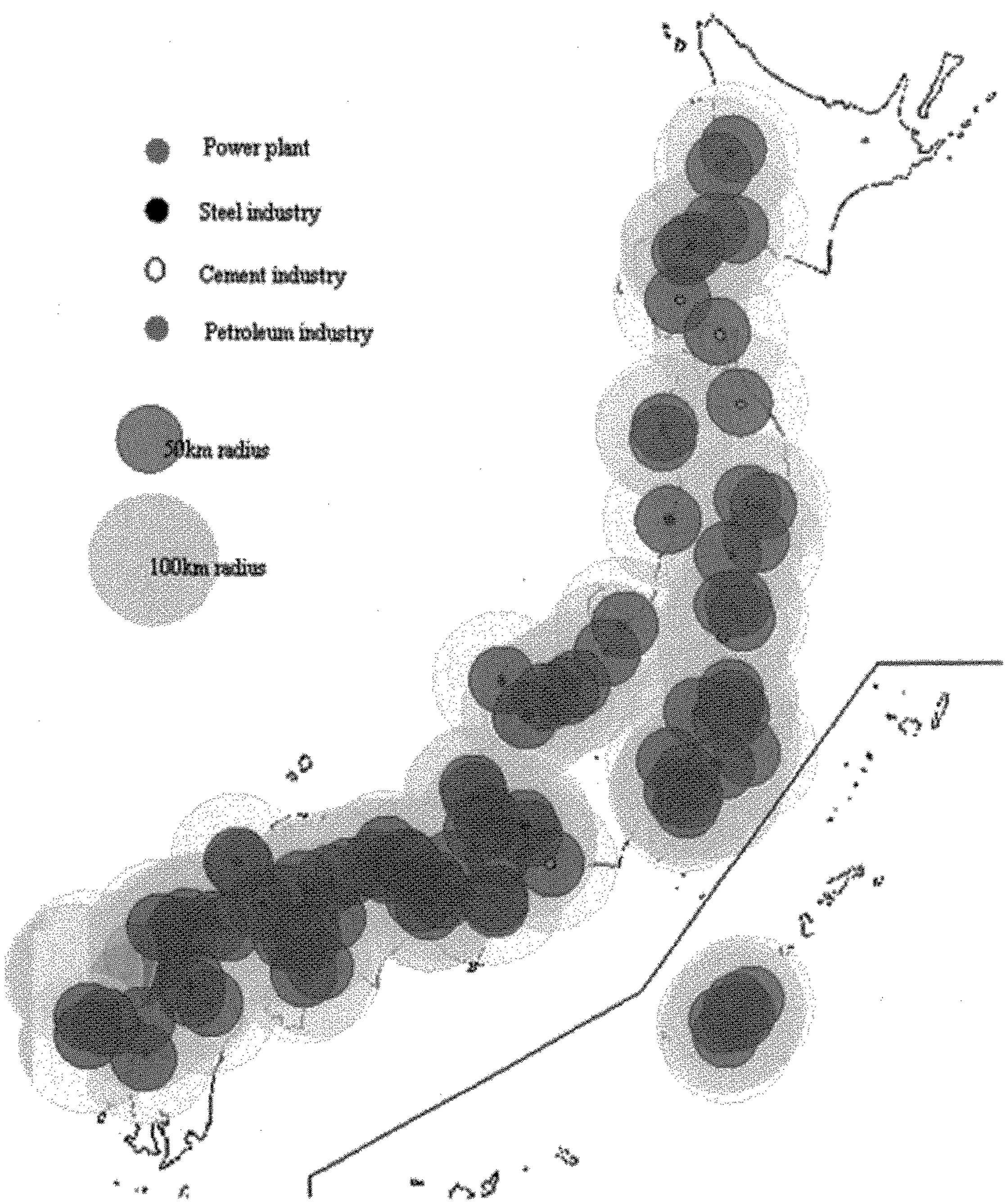

Figure 2 Recycling system of local circulation type by using key industry plants in Japan

REFERENCES

[1] Plastic Waste Management Institute Japan, *PWMI Newsletter*, No.24 (2002).
[2] H. Hotta, *NKK Tech. Report*, **179**, 126-131(2002).
[3] J. Brandrup, M. Bittner, W. Michaeli, G. Menges, *Recycling and Recovery of Plastics*, Hanser, Munich, p.403 (1996).
[4] T. Yoshioka, S. Yasuda, K. Kawamura, T. Sato, A. Okuwaki, *Nippon Kagaku Kaishi* 534-541(1992).
[5] S. M. Shin, T. Yoshioka, A. Okuwaki, *Polym Degrad Stab.*, **61**, 349-353(1998)
[6] S. M. Shin, T. Yoshioka, A, Okuwaki, *J Appl Polym Sci.*, **67**, 2171-2177(1998).
[7] Development of a Method for Treatment of PVC – Hydrochloric Degradation of PVC, Report to DEPA. Stigsæs Industrimiljø A/S. September 1999.
[8] Development of Process for Recycling of PVC, RGS90 Stigsæs Industrimiljø A/S, Final Report-Condensed Version, October 2002.

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