INTEGRATED RECYCLING MANAGEMENT OF INDUSTRIAL SOLID WASTE IN THE CEMENT INDUSTRY

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1. INTRODUCTION

The cement industry represents the most important non-energy industrial source of CO_2 emission. On the other hand, recycling solid waste and by-products can help saving virgin materials and reducing the pollution resulting from dumping in landfills. Cement made by mixing fly ash (FA) and Portland cement is called fly ash cement (FAC), and that made by mixing pulverized water granulated blast furnace slag (BFS) and Portland cement is called blast furnace cement (BFC). In this research, a framework for optimizing and evaluating the environmental impact of FAC and BFC recycling policies in the cement industry is suggested, and demonstrated with a case study.

2. COST-BENEFIT MODEL FOR RECYCLING IN THE CEMENT INDUSTRY

Fig. 1 shows the input-output diagram of materials and energy in the cement industry with the secondary materials FA and BFS resulting from other industries. Inputs include primary and secondary energy (E and E'), and primary and secondary materials (M and M'). Outputs include products (P), solid wastes (W), waste energy (E''), and pollutants (P'). In this research, the cost-benefit analysis of the industrial activities, including recycling, is based on the following simple model. All the inputs of an activity have costs (C) that contribute to the cost of this activity. The benefits of an activity are considered as negative costs. Solid wastes may have positive costs if they are dumped, or negative costs if they are recycled beneficially in other industries. Similarly, the cost of waste energy may be zero if it is not used, or positive if it is used effectively, e.g. heat cascading. Pollutants are evaluated as costs on the basis of the emission weight multiplied by a nominal environmental tax (e.g. Yen 3000/t of CO_2). The environmental tax is expected to be imposed in Japan in the near future. The total cost of an activity should be negative for the activity to be a profitable one. Then the following equation can be used to calculate the total cost of an activity (A):

$$C(A) = C(E) + C(E') + C(M) + C(M') + C(P) + C(W) + C(E'') + C(P') \tag{1}$$

Recycling can be considered as an activity that uses the solid waste output of some other industry as one of its inputs, and produces products that are the input materials of another industry. In many cases, such as the production of blended Portland cement, only minor treatment of the solid waste is necessary, and the main problem is in shipping these materials to the cement plants. These materials are usually shipped by trucks or railways. The consumed energy and emitted pollutants can be assumed proportional to the weight ($x_{i,j}$) of the waste material to be shipped from plant i to plant j, and distance ($d_{i,j}$). The cost of recycling activities of shipping a specific secondary material to plant i is given by:

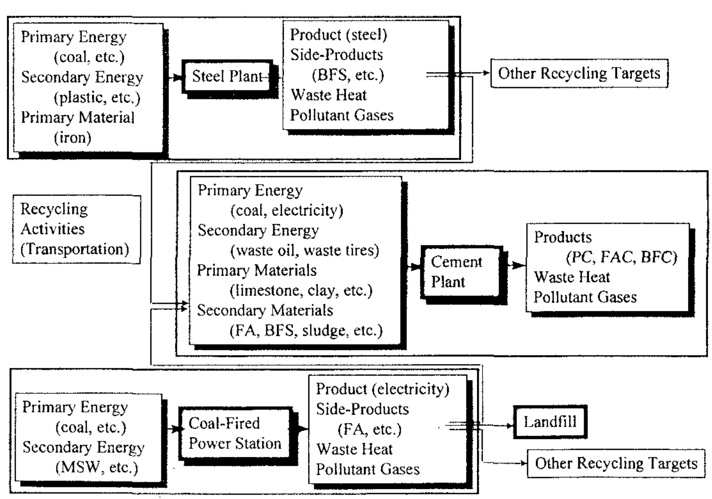

Fig. 1 Input-Output Diagram in the Cement Industry

$$C(shipping) = m_W \sum_j x_{i,j} + (e_{(fuel)} + p_{(truck)} + p'_{(emission)}) \sum_j d_{i,j} x_{i,j} \tag{2}$$

where m_W is the cost per ton of the waste material (W); and $e_{(fuel)}$, $p_{(truck)}$, and $p'_{(emission)}$ are the costs (per $t.km$ of shipment) of the energy, shipping process (by truck in this case), and emission pollutions tax,

Table 1. Weights and Distances of FA and BFS to be Transported to Cement Plants

to \ from		Hokkaido	Tohoku	Kanto	Chubu	Kansai	Chugoku	Shikoku	Kyushu	Total Consumption	Shipments (1000 t.km)	Total Shipment (1000 t.km)
Hokkaido	FA (1000t)	1210.5	0	0	0	0	0	0	0	1210.5		
	BFS (1000t)	513	0	0	0	0	0	0	0	513		
	L (km)	0	726	1099	1482	1675	2021	2007	2304		0	
Tohoku	FA (1000t)	189.5	700	0	0	0	0	0	0	889.5		
	BFS (1000t)	0	0	0	0	0	0	0	0	0		
	L (km)	726	0	373	756	949	1295	1281	1578		137577	
Kanto	FA (1000t)	0	0	70	815.5	0	0	0	0	885.5		
	BFS (1000t)	0	0	7382	0	0	0	0	0	7382		
	L (km)	1099	373	0	383	576	922	908	1205		312336.5	
Chubu	FA (1000t)	0	0	0	2382.75	0	0	0	0	2382.75		
	BFS (1000t)	0	0	0	1922	0	0	0	0	1922		
	L (km)	1482	756	383	0	193	539	525	822		0	
Kansai	FA (1000t)	0	0	0	801.75	0	0	0	0	801.75		
	BFS (1000t)	0	0	0	0	3587	0	0	0	3587		
	L (km)	1675	949	576	193	0	346	332	629		154737.75	
Chugoku	FA (1000t)	0	0	0	0	0	0	0	0	0		
	BFS (1000t)	0	0	0	0	0	5672	0	0	5672		
	L (km)	2021	1295	922	539	346	0	332	283		0	
Shikoku	FA (1000t)	0	0	0	0	0	0	300	0	300		
	BFS (1000t)	0	0	0	0	0	0	0	0	0		
	L (km)	2007	1281	908	525	332	332	0	283		0	
Kyushu	FA (1000t)	0	0	0	0	0	900	0	3000	3900		
	BFS (1000t)	0	0	0	0	0	736	0	3668	4404		
	L (km)	2304	1578	1205	822	629	283	283	0		462988	1067639.25
Total Production	FA (1000t)	1400	700	70	4000	0	900	300	3000	10370		
	BFS (1000t)	513	0	7382	1922	3587	6408	0	3668	23480		
	Clinker (1000t)	5355	8588	14462	11453	6794	5672	16180	28407	96911		

respectively. The costs e, p, and p' depend on the transportation mode, and are higher for heavy trucks than for cargo trains. Applying this equation in the case of a cement plant with two secondary materials (FA and BFS), the cost of shipping activities of secondary material to plant i is given by:

$$\mathrm{C(shipping)} = m_{(FA)}\sum_j x1_{i,j} + m_{(BFS)}\sum_k x2_{i,k} + (e_{(fuel)} + p_{(truck)} + p'_{(emission)})(\sum_j d_{i,j}x1_{i,j} + \sum_k d_{i,k}x2_{i,k}) \quad (3)$$

where $d_{i,j}$ and $d_{i,k}$ are the distances between cement plant i, and coal-fired power station j and steel plant k, respectively; $x1_{i,j}$ and $x2_{i,k}$ are the weights of FA and BFS shipments from power station j and steel plant k to cement plant i, respectively.

3. CASE STUDY

The aim of the case study is to evaluate the impact of maximum recycling of FA and BFS in the cement industry. In order to simplify the case study, the data are aggregated into eight zones corresponding to the Japanese administrative districts. The case study is based on the following assumptions: (1) At each district, cement plants are located fairly close to the sources of FA and BFS so that the shipments within the same district can be neglected; (2) All plants in one district are located near the largest city in that district; (3) The FA and BFS to be recycled will be directly shipped by trucks from their originating points to the cement plants through the national road network; (4) The quantities of FA are assumed double the present values at each district. This assumption is based on the fact that many coal-fired power stations are under construction in Japan and are expected to double the annual FA production within a few years. The quantities of BFS and clinker are expected to remain stable; and (5) All the produced FA and BFS will be recycled with 20% and 50% mixing ratios in the FAC and BFC, respectively. The problem of minimizing the shipping cost of FA and BFS from coal-fired power stations and steel plants to cement plants, subject to supply and demand constraints is solved.

Table 1 shows the results of the optimization. In this table, the weights and distances of FA and BFS shipments to the cement plants are shown.[1),2)] The total minimun amount of shipment of FA and BFS in a year is about 1 billion *t.km*. It can be noticed that, because of the large production of cement in Japan, it is possible to recycle most of the FA and BFS within the same district. The situation is expected to change in the future when the cement production in Japan will start to decrease, while FA production continues to increase due to increasing energy demands.

4. CONCLUSIONS

The following conclusions can be stated: (1) A cost-benefit model for recycling industrial solid wastes in the cement industry was developed taking into account the environmental impact. (2) The case study showed that, because of the large production of cement in Japan, it is possible to recycle most of the fly ash and blast furnace slag within the same district.

REFERENCES

1) Coal Ash Handbook (1995). Japan Fly Ash Association, Tokyo (in Japanese).
2) Steel Slag Guidebook (1995). Steel Slag Association (in Japanese).