Transactions of the Materials Research Society of Japan 29[5] 1849-1852 (2004)

Environmental and Economic Analysis of Zero-Emission Chemical Recycling Technology for Waste Plastics From Used Electrical Appliances and Automobile Shredder Residue

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Abstract

Recycling of waste plastics from household electrical appliances and automobile shredder residue is a major concern in Japan. Japanese industry has developed zero-emission chemical recycling technology for waste plastics (including flame-resistant plastics) with the financial support of the Ministry of Economy, Trade and Industry. Life cycle assessment and project finance methods were used to analyze the environmental impacts and economic feasibility of this technology in comparison with conventional technologies. Chemical (Br) recovery in conjunction with energy recovery by this technology could lead to a significant reduction in CO_2 emissions compared with those from conventional incineration. However, CO_2 emission reduction by this recycling technology is not superior to that from landfill. The economic feasibility of this technology is strongly dependent on income from waste plastics and cost of electricity.

Key words: bromine, chemical recovery, electricity recovery, LCA, IRR, waste plastics

INTRODUCTION

The Law for Recycling of Specified Kinds of Home Appliances came into force in April 2001 in Japan. Since then, all waste TVs, refrigerators, air-conditioners, and washing machines have to be collected and brought to specific recycling facilities. In addition, a law for the recycling of automobiles will soon come into force. These laws will encourage manufacturers to increase the recycling of products at the end of their lives. One of the major concerns is the recycling of plastics from waste home appliances and automobile shredder residue (ASR). Some of the waste home appliances – especially TVs – and automobiles incorporate parts made of flame-resistant plastics containing bromine (Br). Bromine is an intractable waste that must be landfilled.

Recently, Japanese industry has developed zero-emission chemical recycling technology for waste plastics (including flame-resistant plastics) with the financial support of the Ministry of Economy, Trade and Industry. This technology uses a high-temperature gasification–melting furnace, and can recover energy (as electricity) and chemicals (Br etc.) simultaneously from waste plastics containing bromine with almost no dioxin emissions. Case studies were conducted to analyze the environmental impacts and economic feasibility of this technology by life cycle assessment (LCA) and project finance methods in comparison with those of conventional technologies.

OVERVIEW OF THE RECYCLING TECHNOLOGY

Figure 1 shows a schematic diagram of the recycling technology. It consists of three processes: gasification of waste plastics, wastewater treatment, and bromine recovery. Partial oxidation occurs in the furnace. Owing to the rapid, high-temperature gasification of waste plastics and the quenching of the synthesized gas, there is little possibility of dioxin emissions. The gas is burned to generate electricity. The bromine contained in the waste plastics is collected as bromide in the fly ash generated by the furnace, and is further treated in the wastewater treatment process and the bromine recovery process. Other materials, such as metals contained in the waste plastics, are also recovered.

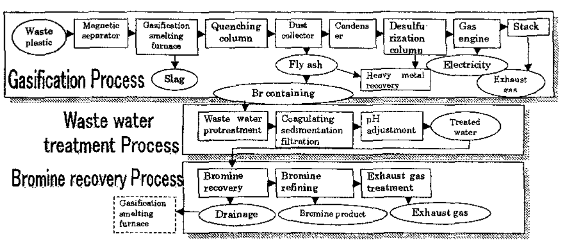

Fig.1 Schematic diagram of the recycling technology

DETAILS OF CASE STUDIES

Implementation of the recycling technology in Yamaguchi Prefecture was investigated in this work. We assumed 50,000 t processed per year (50% from the recycling facilities for home appliances and 50% from ASR), 313 running days per year, and 24-hour continuous operation. The average concentration of bromine contained in the waste plastics was set at 1%. The places where the waste plastics and ASR would be collected were chosen in such a way that the transport distance to the recycling plant was minimized.

The conventional technologies of landfill, incineration, and incineration with electricity recovery (energy efficiency, 10%) were compared with the recycling technology. The transport distance was assumed to be 20 km.

ANALYSES OF ENVIRONMENTAL IMPACTS

The environmental impacts of CO_2 emissions from the recycling technology and conventional technologies were investigated by LCA. Figure 2 shows the system boundaries. The functional unit was the processing of 1 t of waste plastics.

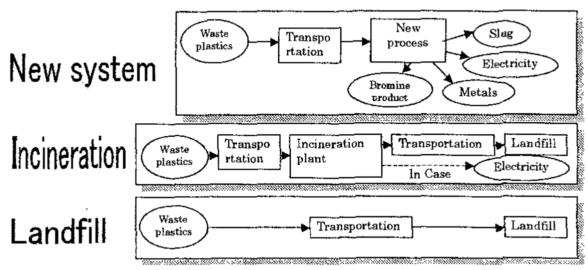

Fig. 2 System boundaries of objective systems

In the recycling process, electricity, bromide slag, and iron would be recovered. These outcomes would result in the saving of virgin materials and energy consumption, and in the avoidance of emissions to the environment. The outcomes of the conventional and recycling systems were compared with the CO_2 emissions associated with the production of an equivalent amount of virgin materials, so that overall savings could be estimated.

The data for inventory analyses (material balance and energy balance) were obtained on the basis of interviews and a literature survey [1, 2]. Most background data were provided by LCA software [3].

ANALYSES OF ECONOMIC FEASIBILITY

A cash-flow analysis technique based on project financing was used to investigate the economic feasibility of the recycling system. Internal rate of return (IRR) was chosen as one of the indexes to evaluate economic feasibility. IRR is defined as the discount rate that makes the net present value of cash flows over time equal to zero. Various factors were considered in the cash-flow analysis, including expenditure related to plant construction, maintenance, auxiliary fuel, labor, land occupation, interest rates, taxes, and incomes from disposal cost of waste plastics, recovered materials, and electricity. Data on these expenditures and incomes were obtained through interviews and statistics reflecting the current situation in Yamaguchi Prefecture and Japan. Since electric power companies in Japan currently purchase electricity generated from industrial wastes in few cases, the value of electricity recovered by this recycling system was uncertain. Therefore, the following two electric power values were used: 6.0 yen/kWh (cost of utility power) and 3.5 yen/kWh (cost of surplus power). Transport expenses of the waste plastics and ASR were not considered, because they are the responsibility of the waste suppliers.

RESULTS AND DISCUSSION

1. Environmental impact

Figure 3 shows CO_2 emissions from the processing of 1 t of waste plastics by each system. The recycling system reduces CO_2 emissions greatly compared with the incineration system. Incineration with electricity recovery reduces CO_2 emissions, but the recycling system emits less CO_2 unless the efficiency of electricity recovery by the incineration plant exceeds 12.3%. On the other hand, CO_2 emissions by the recycling system were larger than those from landfill. Figure 4 shows the details of CO_2 emissions from the recycling system. Waste plastics and auxiliary fuel are the major sources of CO_2 emissions. Reduction of CO_2 emissions is attributable mostly to electricity recovery. The CO_2 emission intensity of bromine recovery by this recycling process is small (0.53 kg-CO_2 / kg-Br_2) compared with that of the conventional process (8.4 kg-CO_2 / kg-Br_2).

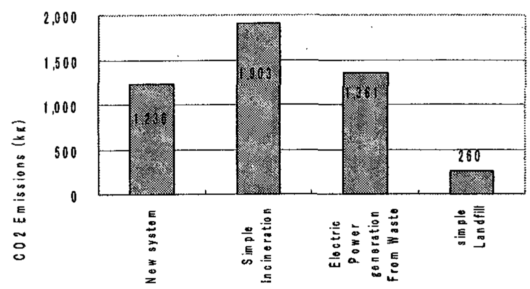

Fig.3 CO_2 emissions for the recycling system and conventional systems

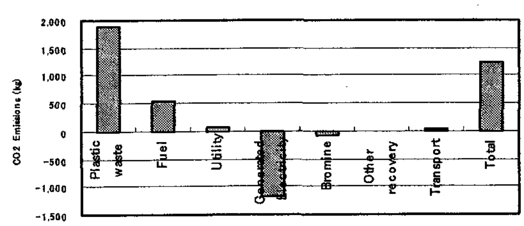

Fig.4 Details of CO_2 emissions for the recycling system

2. Economic feasibility

Figure 5 shows the income and expenditure for the recycling system when the electricity value is 6.0 yen/kWh. Eighty percent of income comes from disposal cost of waste plastics, 15% from electricity recovery, and 5% from bromine recovery. Facility-related expenses account for most of the expenditure, followed by utility expenses.

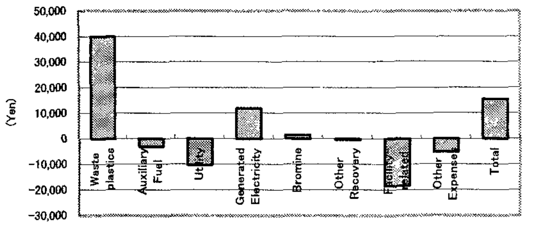

Fig.5 Details of incomes and expenditure for the recycling system (electricity rate: 6.0 Yen/kWh)

Figure 6 shows the results of IRR analyses. Sensitivity analyses were conducted on the value of electric power, which contributed to most of the total profits. IRR is strongly dependent on the income by disposal cost of waste plastics and the sale price of electricity. From the viewpoint of economic feasibility, the IRR of the recycling system should exceed the target (here, 3%). If the value of electricity is 3.5 yen/kWh, IRR would not exceed 3% unless the income from disposal cost of waste plastics were more than 34,000 yen/t. On the other hand, if the value of electricity were 6.0 yen/kWh, IRR would exceed 3% if the income by disposal cost of waste plastics were more than 29,000 yen/t.

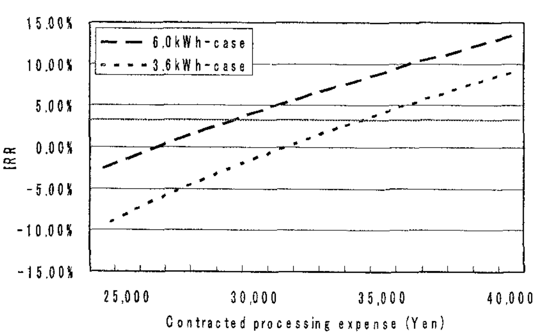

Fig.6 Results of IRR analysis

CONCLUSIONS

Bromine recovery and electricity recovery by the recycling technology could lead to significant reduction of CO_2 emissions compared with those from conventional incineration. The economic feasibility of this technology is strongly dependent on income from disposal cost of waste plastics and the value of electricity.

ACKNOWLEDGMENTS

This study was conducted as part of the project "Development of Zero-emission Chemical Recycling Technology for Electrical, Electronic, and Automotive Post-use Plastics", financially supported by the Chugoku Bureau of Economy, Trade and Industry.

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(Received October 10, 2003; Accepted October 31, 2003)