UDC 678 : 662 . 741

Plastics Recycling by a Coke-Oven from Waste Plastics to Chemical Raw Materials

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Abstract

Plastics recycling by a coke-oven from waste plastics into chemical materials has been developed to solve the problems of waste plastics and as a step toward protect the environment from global warming caused by the reduction of CO_2 emissions. Plastics are thermally decomposed in coke-ovens into oil, gas and cokes. These are effectively used in chemical plants, power plants and blast furnaces in the Works. The recycling process for container and package plastics in municipalities has been successfully operated and contributes to the favorable recycling of waste plastics.

1. Introduction

The annual production of plastics in Japan is about 15 million tons, which is approximately equivalent to the volume of domestically produced steel (about 100 million tons per year). While the annual domestic consumption of plastic products is nearly 11 million tons, roughly 9.5 million tons of waste plastic is generated in Japan annually[1], which means that a notable portion of plastic products is used and disposed as waste without accumulating as social stock. Small portions of industrial waste plastics, which are not mixtures of different plastic materials and the composition of which is identified, are recycled in a limited percentage. However, the remainder is either incinerated or dumped as landfill. Regarding waste plastics discharged from households, substantially all are either incinerated or dumped.

Under such circumstances, the treatment of waste plastics constitutes a serious problem, when considerating factors such as the shortage of landfill sites and the hazardous nature of some incineration exhaust gasses. In order to promote the recycling of plastic containers and packages (roughly 3.3 million tons per year[2]) discharged as a part of general waste, forming a part of the 9.5 million tons per year of waste plastics, the Law on Recycling Containers and Packaging was enforced to its full extent from April, 2000. According to the law, households are to classify and discharge plastic containers and packages and municipalities are to collect and treat them for resource recovery.

Meanwhile, the control of carbon dioxide emission is an important environmental issue as one of the important measures to stem global warming; the Japan Iron & Steel Federation has targeted an increase in the use of recycled plastics to approximately 1 million tons, annually, so by the year 2010 in their contribution to worldwide efforts in suppressing carbon dioxide that is emitted by the incineration of plastic.

For the purpose of fulfilling two important social responsibilities, namely, to alleviate waste disposal problems and to prevent global warming by reducing the carbon dioxide emissions, Nippon Steel turned its attention to the reuse of waste plastics and as a result, developed a plastic recycling technology to produce chemical raw materials using coke ovens. The developed technology named the Coke-Oven from Waste Plastics to Chemical Raw Materials Method has been used for the recycling of plastic containers and packages since November, 2000. This paper reports the outline of the technology.

2. Treatment of Plastics for Recycling by Steelmaking Process

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Through the joint research[3] between the Japan Small and Medium Enterprise Corporation and the city government of Okegawa (in Saitama Prefecture) and the joint experimental study[4] with Japan Waste Research Foundation and the city government of Tachikawa (Tokyo Metropolitan Prefecture), Nippon Steel has confirmed the effectiveness of the liquefaction method or the thermal decomposition method, which constitutes the main stay technology for the Law on Recycling Containers and Packaging at its initial stage, as a technique for the plastics recycling. Then, directing attention to coke ovens, which are a carbonization furnace having a thermal decomposition function, Nippon Steel conducted recycling tests of general waste plastics using coke ovens to confirm their versatility and as a result, established the Coke-Oven from Waste Plastics to Chemical Raw Materials Method for thermally decomposing plastics in the coke ovens[5,6].

The steel industry produces steel materials using iron ore and coal as main raw materials and here, coal is carbonized into coke, which is then used as an agent for reducing iron ore. In the carbonization process, hydrocarbon oil and coke oven gas are generated and recovered as by-products. The oil is used as a raw material at chemical plants and the gas is burned as a source of power. Thus, a steel works constitutes a system in which chemical plants and gas utilization facilities (power plants) form integral parts. The effectiveness of the steelmaking process for the recycling of waste plastics can be summarized as follows:

1) A steel works is a large-scale plant operated around the clock and is designed to fully utilize the large amount of energy the raw materials used therein contain. Additionally, a steel works possesses the technologies for the recycling of virtually all the materials it uses or generates from the production processes such as gasses, by-products and industrial water. Thus, the steel industry is one of the most energy-efficient of industries and has the process basis for producing marketable products from waste.

2) A steel works is a system in which chemical plants and gas utilization facilities (power plants) form integral parts together with steelmaking processes, and by-products are supplied to society in general as goods produced under strict quality controls and assurances.

3) Plastics are composed mainly of carbon and hydrogen, and coal, which is composed substantially of the same elements, is used in a steel works in great quantities.

4) A closed loop transportation network can be formed by utilizing the return trips of steel product delivery for the collection of waste plastics.

Fig. 1 shows the whole material flow of the waste plastic recycling process when it is incorporated in the steelmaking process.

3. Recycling Flow of Plastics

The basic processes of plastics recycling at a steel works comprise (1) collection, (2) pretreatment of sorting and briquetting and (3) thermal decomposition in coke ovens.

3.1 Collection

Households discharge waste plastics classified according to guidelines set forth by local municipalities, and the municipalities roughly sort to remove excessive foreign matter and reduce the overall volume and then compact (or bale) using a compressor to enable a more efficient transport and storage of plastic waste products.

The conditions for classifying and baling vary widely between municipalities, as shown in **Table 1**, depending on the size thereof (population, land area, etc.), collection methods and the capacity of existing waste treatment facilities, among other conditions. Therefore, the conditions for accepting and transporting to steel works are decided by each municipality, though conditions are to some degree agreed to by all parties in advance. Presently, in consideration of the amounts and frequency of collection at each municipality, waste plastics are transported to steel works by road, periodically, in lots varying between 5 and 10 tons, according to truck capacity.

The classification method in the collection stage and the extent of the rough sorting have influence on the quality of baled waste plastics such as inclusion of foreign matter and contamination, and the capacity of the compressing/baling facility on the shape and bulk density of the bales. Pretreatment before the thermal decomposition is done at the steel works according to the different bale conditions of the various municipalities. Subsequently, the quality information relating to waste plastics is fed back to each municipality, with the objective of establishing a framework for continuously improving the quality of the waste plastics. The cooperation of households for the classified discharge of waste plastics is very important to the smooth functioning of the whole system; Nippon Steel is working to engage local communities to encourage their further involvement in the recycling process by providing them with activities that will stress the importance of recycling with regard to their living environments[7,8].

As of the fiscal year 2001 (April 2001 to March 2002), some 350 municipalities took part in the plastic containers and packages recycling program[9]. These municipalities exist over a wide area all over Japan, as is illustrated in **Table 2**. This means that collection networks covering wide areas are necessary for the recycling treatment

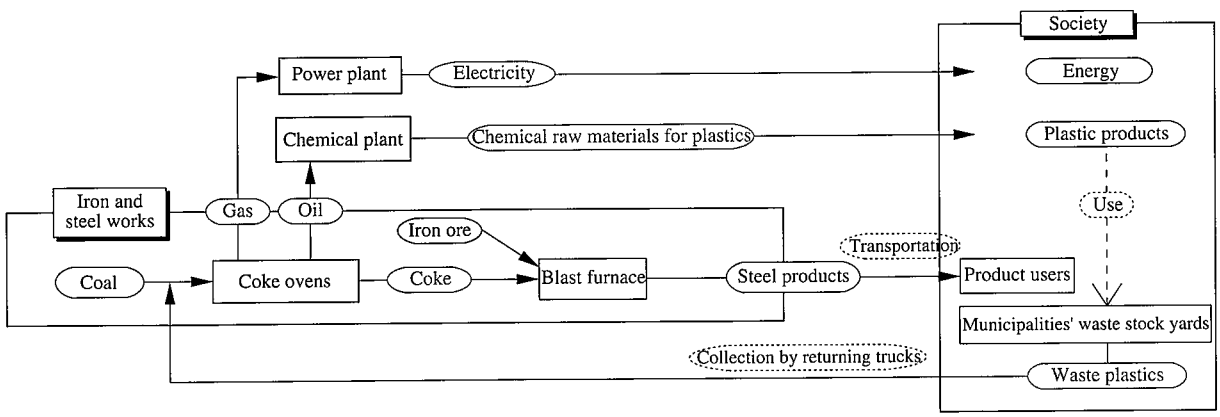

Fig. 1 Overall flow of plastics recycling

Table 1 Plastics collection conditions of municipalities

Planned annual collection amount	Smallest: 1 t (A Town) Largest: 35,000 t (B City)
Collection objects	Plastic containers and packages Any plastics Certain kinds of plastic containers and packages specified by municipality
Rough sorting method	Manual, mechanical
Bale shape and size	600 × 400 × 300 mm Rectangular solid, roughly 600 × 400 × 600 mm Rectangular solid, roughly 1,000 × 1,000 × 1,000 mm Rectangular solid, roughly Round baleg

Table 2 Geographical distribution of municipalities

District	Number of municipalities
Hokkaido	34
Tohoku (Northeast of Honshu)	24
Kanto (around Tokyo)	51
Ko-shin-etsu (center of Honshu)	71
Chubu (around Nagoya)	58
Kinki (around Osaka)	37
Chugoku (around Okayama, Hiroshima)	31
Shikoku	17
Kyushu	32
Total	355

at steel works. For this end, utilizing return trips of empty trucks having delivered steel products is effective for bringing the waste plastics to steel works. As seen in **Fig. 2**, in the basic transportation routes of the waste plastics from municipalities, the return trips of the empty trucks after delivering steel products are used for reducing the environmental loads of truck exhaust gas and noise and saving energy consumption. In the Kanto area, where the transportation volume is large, about 90% of waste plastics are transported utilizing the return trips of the empty trucks.

3.2 Pretreatment Process

Collected waste plastic containers and packages are a mixture of containers and packages of various kinds of plastics and their shapes and chemical compositions are widely varied. Therefore, metals, inorganic substances and food residues are inevitably found among the waste plastic, despite the efforts to classify and sort at home and at the point of pickup. In view of this, for the purpose of protecting the coke ovens, the equipment for the pretreatment is designed to remove foreign matter and to form plastic into briquettes of a size suitable for charging into coke ovens (see **Fig. 3**). In the equipment configuration, emphasis is given to removing foreign matter by manual and mechanical sorting, and the technologies to classify various kinds of plastics from general waste plastics accumulated through

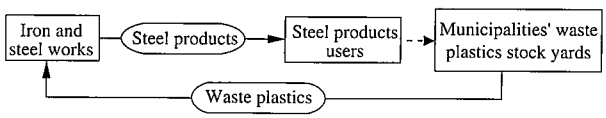

Fig. 2 Transportation of steel products and waste plastics collection route

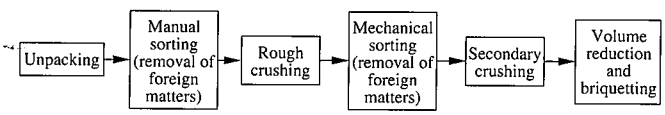

Fig. 3 Process flow of pretreatment

the joint research[3] with Japan Small and Medium Enterprise Corporation and the city government of Okegawa and the joint experimental study[4] with Japan Waste Research Foundation and the city government of Tachikawa were reflected in the equipment design.

The process sequence of the pretreatment is as follows: waste plastics accepted in the form of bales are unpacked and unbagged, eliminated of identifiable foreign matter by manual sorting, crushed to 100 to 200 mm by a rough crusher, eliminated of magnetic metals by a magnetic classifier and of inorganic matter by vibrating screens, crushed to 20 mm or so by a secondary crusher, and then formed into briquettes tens of millimeters in diameter to reduce the overall volume and to ease their handling in the in-plant and in the charging into coke ovens. The capacity of the briquetting is 8.4 t/h. The pretreatment equipment does not include any furnace or treatment process using water so as not to discharge any exhaust gas or waste water for reducing environmental load.

3.3 Thermal Decomposition Process (Coke Ovens)

The plastic briquettes of a prescribed shape and size are charged into the coking chambers of coke ovens shown in **Fig. 4** together with coal. The details of a coking chamber are shown in **Fig. 5**. A coking chamber is shielded from the air, and the material therein is heated indirectly through brick walls on both the sides. Thus, the plastics are thermally decomposed at temperatures from 1,100 to 1,200°C in a reducing atmosphere without burning to yield hydrogen and hydrocarbons. The decomposition products in the form of a high temperature gas of about 900°C are recovered through the top of the coking chamber, cooled rapidly to 80°C or below with water and further, to about 35°C by a gas cooler. Any liquid components in

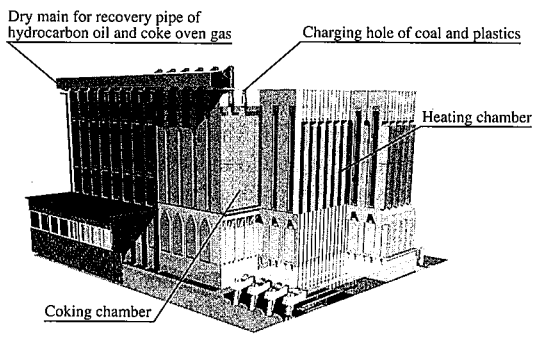

Fig. 4 Structure of coke oven battery

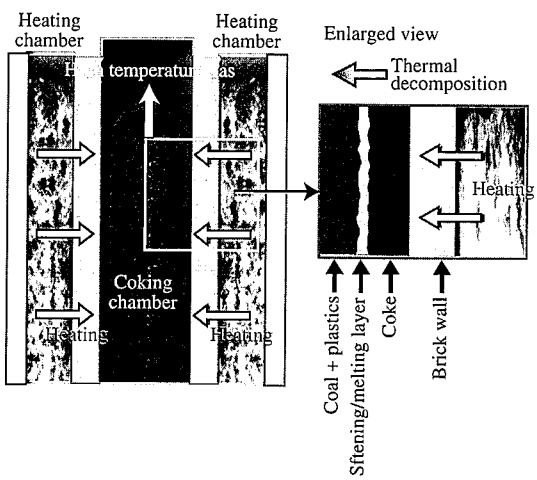

Fig. 5 Thermal decomposition process in coke oven

the gas condense during the cooling and are separated by oil-water separation. The oil components are recovered in the form of tar. Then, gas oil is recovered from gas components after naphthalene recovery and desulfurizing processes, and the remaining components in the form of gas at ordinary temperatures are recovered as coke oven gas.

Plastics are decomposed, roughly, into 40% oil, 40% gas and 20% coke[5], and virtually all of these can be used as resources. The oil consists mainly of tar and gas oil, and can be used as the raw materials of plastic, paint and the like at chemical plants. The gas, which consists mainly of hydrogen and methane, has a high calorific value and is used for power generation. The coke is used in blast furnaces as a reducing agent.

For reference, coal is decomposed, roughly, into 5% oil, 10% gas and 75% coke**10**). Plastics yield oil and gas in higher ratios, presumably because plastics contain less percentage of aromatic hydrocarbons than coal. The thermal decomposition of plastics is characterized by the higher recovery ratios of oil and gas.

4. Actual Recycling Treatment Record

In the fiscal year 2001, Nippon Steel's Kimitsu Works collected and processed waste plastics from 80 municipalities having populations ranging from 2,000 to 600,000 (See **Fig. 6**).

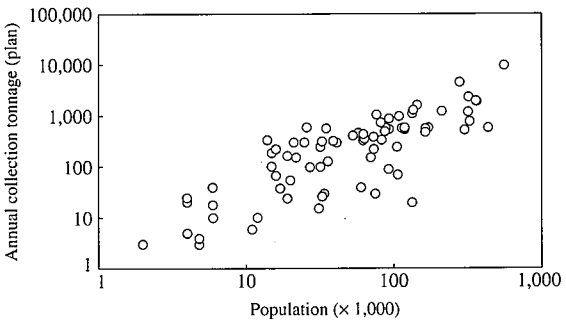

Fig. 6 Collection tonnage by municipality (plan)

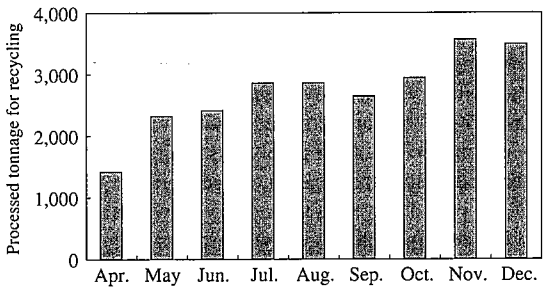

Fig. 7 Change of waste plastics treatment amount at Kimitsu Works in FY 2001

As seen in **Fig. 7**, the amount of recycled plastics increased monthly as it became more common for families to sort their waste. This resulted in a monthly processing amount exceeding 3,000 t, thereby greatly contributing to the reducing in the dumping and incineration of waste plastics.

5. Summary and End Remarks

In order to meet the social requirements to alleviate waste problems and to stem global warming through the reduction of carbon dioxide emission, Nippon Steel took up the challenge to effectively utilize waste plastics and as a result, established a technology to recycle plastics using the existing steelmaking process employing coke ovens. The technology consists of thermally decomposing waste plastics in coke ovens into oil, gas and coke for use as a material, and is effectively applied to the enterprise of the recycling treatment of plastic containers and packages discarded and collected throughout Japan.

The recycling business was promoted by working closely with municipalities and local residents, and the treatment method was appreciated thanks to large and stable treatment capacity and the conversion of waste plastics into chemical raw materials and electricity that can be reused by society in general. The process does not require any excessively strict classification in the discharge and collection of waste plastics and thus, the actual state of waste handling of municipalities and local residents need not be significantly changed in the plastics recycling activities. According to some reports, waste generation has decreased recently[11]. Nippon Steel intends to expand the plastics recycling business, again by working closely with municipalities, local residents and related parties to contribute to alleviating the problems of waste and global warming.

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