Recycling of Waste Plastic Packaging in a Blast Furnace System

Yoji Ogaki*, Koichi Tomioka*,
Atsushi Watanabe**, Koji Arita***,
Ichiro Kuriyama**** and Tetsuro Sugayoshi*****

Since October 1996, NKK has been operating a recycling system of industrial waste plastics as raw material for blast furnace. This NKK's recycling technology, in which waste plastics are used as a substitute for coke, a reducing agent of iron ore, has been officially authorized as a recycling method under the PWRL (Packaging Waste Recycling Law), and is now going to be applied to recycling of waste plastic packaging. A new technology of removing impurities, especially PVC, has become a key element in applying recycling system of waste plastic packaging to blast furnaces. Both at Fukuyama and Keihin Steel Works, NKK has constructed a new treatment plant to cope with the full implementation of the PWRL in April 2000.

1. Introduction

Waste plastic, both from industrial and municipal sources, amounted to approximately 9.5 million tons in 1997. Of this figure, 34% (approximately 3.25 million tons) was disposed of by burying in landfills, and the remaining 6 million tons incinerated, approximately 2.8 million tons being used to generate electricity or for thermal recovery. Even if the recycled proportion is included, only little more than 40%, or 4 million tons, was used effectively in some manner[1].

The Packaging Waste Recycling Law was fully implemented in April 2000 within this context. The use of all plastic packaging other than PET bottles' as reducing agents for blast furnace is approved under the provisions of this law.

2. Use as a reducing agent in blast furnaces

2.1 Blast furnaces

As shown in **Fig. 1**, iron ore and coke are loaded into the blast furnace from the top in alternate layers, and hot air from the tuyeres at the base of the furnace fed in to generate CO gas from the coke, the heat of this reaction and the CO being used to reduce and smelt the iron ore. The pig iron and slag thus produced are removed at intervals via an outlet at the base of the furnace. Currently, all steel companies inject pulverized coal via the tuyeres as a substitute for coke, thus reducing the cost of raw materials.

The No. 1 blast furnace at the NKK Keihin Works consumes approximately 4000 tons/day of coke and 1000 tons/day of pulverized coal, reducing 16000 tons/day of iron ore, and producing 10000 tons/day of pig iron.

Waste plastic may be used in place of coke and pulverized coal after forming into particles of the required size, either by crushing or pelletizing as necessary, and subsequently injected into the blast furnace from the tuyeres with hot air using specialized injection equipment. The injected plastic is broken down to form re-

* Manager, Recycling Business Project Dept.
** Manager, Technology Planning and Coordination Dept.
*** General Manager, Environmental Project Planning & Marketing Dept.
**** Manager, Environmental & Recycling Plant Engineering Dept.
***** General Manager, New Business Center

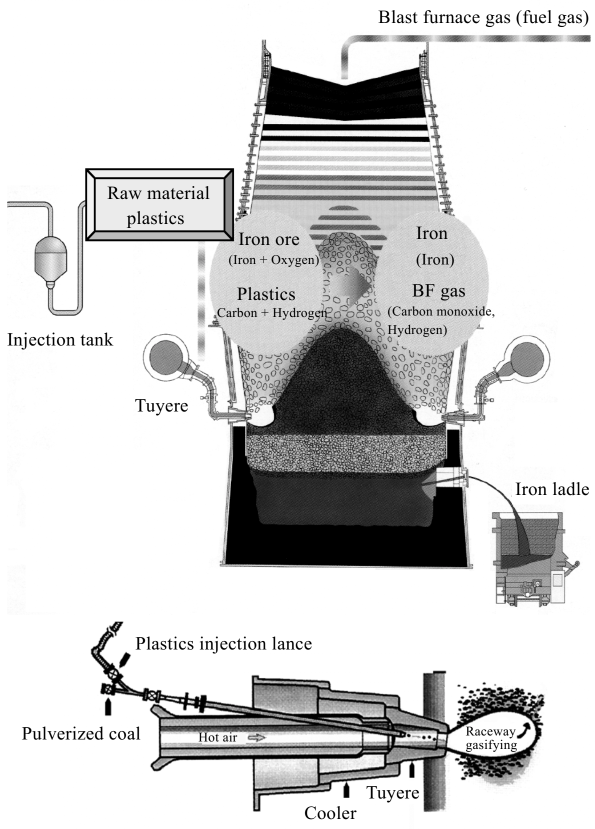

Fig. 1 Blast furnace process and tuyeres

ducer gas ($CO + H_2$) which rises through the raw materials in the furnace and reacts with the iron ore.

Following the reduction reaction, the gas (approximately 800 kcal/Nm^3) is recovered at the top of the furnace, and reused as fuel gas in heating furnaces and generators within the steel plant.

2.2 Iron ore reduction reaction

Hot air is injected at high speed through the tuyeres at the base of the blast furnace, fluidizing the coke and forming a space referred to as the "raceway." The plastic particles injected via the tuyeres are completely gasified during rotation within the raceway[2].

Pulverized coal or coke is burnt rapidly in the first stage of the raceway, consuming oxygen and generating CO_2 at temperatures in excess of 2000℃.

$$C + O_2 \rightarrow CO_2$$

As all oxygen has been consumed by the last stage of the raceway, CO is produced by reaction with the coke.

$$C + 2CO_2 \rightarrow 2CO \text{ (coke, pulverized coal)}$$

Plastic is broken down into CO and H_2.

$$1/2C_2H_4 + CO_2 \rightarrow 2CO + H_2$$

(polyethylene employed in this example)

The CO and H_2 generated rises within the furnace, reducing and smelting the iron ore. The pig iron produced is removed from the base of the blast furnace.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$$

(coke, pulverized coal)

$$Fe_2O_3 + 2CO + H_2 \rightarrow 2Fe + 2CO_2 + H_2O$$

(plastic)

When plastic is used the hydrogen contributes to the reduction reaction, thus reducing the amount of CO_2 generated by approximately 30% in comparison with use of coke and pulverized coal alone.

2.3 Functional substitution of coke and efficiency of use of resources

As described above, plastic may be substituted in the coke reduction reaction. The efficiency of utilization of the reduction gas is generally fixed at approximately 60% by the equilibrium of reaction with iron oxide.

After removal of dust from the furnace gas following the reduction reaction it is used as fuel gas within the steel plant. Efficiency of utilization has been calculated as 20% in this case, with overall efficiency of utilization reaching approximately 80%.

In addition to reducing and melting the iron ore, coke also functions as a spacer to ensure this movement of gases, liquids, and solids within the blast furnace. Plastic and pulverized coal are unable to function in this manner, and substitution of coke with plastic is therefore limited to approximately 40%. Application of this figure to the No.1 blast furnace at the NKK Keihin Works, currently producing 3 million tons of pig iron annually, would allow recycling of 600000 tons of plastic each year.

2.4 Items unsuitable for use as raw material for blast furnace

Injection of chlorine-contained plastics such as PVC in blast furnaces generates hydrogen chloride due to the decomposition of the plastic with heat, same as with other thermal processes. The limestone used in the blast furnace to control the composition of the slag neutralizes the hydrogen chloride in the furnace and decrease its concentration.

As the temperature in the vicinity of the tuyeres is approximately 2400℃, the presence of hydrogen chloride does not result in production of dioxins. Furthermore, as the reducing atmosphere in the low-temperature region at the top of the furnace contains no oxygen, no dioxins are produced, and the re-synthesis reaction does not occur. This is extremely effective in preventing the synthesis reaction of dioxins at all locations within the furnace.

As no countermeasure are taken against hydrogen chloride corrosion of equipment used in the treatment and utilization of blast furnace gas, it is important to ensure that the recycled materials used contain the absolute minimum of chlorine-contained plastics. Most other plastics, including PET plastics unsuitable for liquification, may be used as reducing agents. Small amounts of paper, stones, and sand included with the plastics present no problems as they are simply discharged as slag.

2.5 Treatment of industrial waste plastic

Operations to convert industrial plastic waste except for PVC to blast furnace reducing agents were commenced at the No. 1 blast furnace at the NKK Keihin Works in October 1996. Approximately 40000 tons of plastics are now recycled as blast furnace reducing agents.

The equipment employed in converting the materials to blast furnace reducing agents is shown in **Fig. 2**. Solid plastics (e.g. bottles) are reduced to the required particle size in a shredder, and injected directly into the furnace. In order to avoid problems with blockages in piping, plastics in film format are melted and formed into pellets of the required size for injection into the furnace. Components of industrial waste plastics are always clearly known, and admixture of PVC plastics may therefore be avoided when the materials are received. Equipment for the removal of PVC has therefore not been installed.

Contracts have been concluded with more than 300 companies in sectors such as electric, communications,

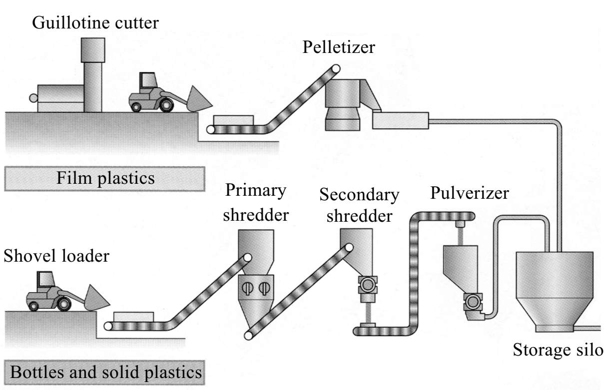

Fig. 2 Equipment for conversion of industrial waste plastics to blast furnace material

motor vehicles, machinery, chemicals, printing, plastics product manufacture, and supermarkets. These companies are located throughout the entire country.

Plastic scrap is obtained from the manufacturers of office automation equipment, bumpers, hangers, plastic tanks, components, plastic moldings, PET bottles, detergent containers, plastic sheeting (for industrial and construction applications), aluminum and paper laminated materials, magnetic tape, packaging materials (packaging bands, plastic bags, expanded styrofoam), and sheet film etc.

3. Recycling system of plastic packaging materials other than PET bottles as blast furnace reducing agents

3.1 Definition of 'plastic packaging materials other than PET bottles'

'Plastics other than PET bottles' is defined as plastic bottles, containers, cups, tubes, and bags used in association with the marketing of products. Class 2 PET bottles used for soft drinks, liquor, and soy sauce are sorted and collected independently, and recycled for further use as PET resin products, and are therefore handled separately. At the same time, plastics employed in hand basins and plastic goods etc., are also excluded.

3.2 The packaging waste recycling law

The general flow of recycling for plastic packaging materials other than PET bottles as defined under the Packaging Waste Recycling Law is shown in **Fig. 3**.

Plastic packaging waste is sorted by the consumer and collected by municipalities. It is then checked against the sorting criteria and stored. Designated companies (companies using plastic packaging materials for marketed products, or manufacturing such materials) are then responsible for the cost of recycling materials, which are sorted within criteria suitable for recycling. The designated companies can either recycle the material on their own, or pass the materials to the recycling companies. The Japanese Container and Packaging Recycling Association is engaged in facilitating the recycling operations of municipalities, designated companies, and recycling companies.

Municipalities have contracts with the Association to receive materials conforming to the sorting criteria. Recycling companies are registered with the Association and bid for the materials for recycling, and handle the recycling of items satisfying the recycling criteria. The association receives 94% of the cost involved in accepting materials for recycling from the designated companies, the remaining 6% of these expenses being received from municipalities to cover the costs of small businesses excepted from recycling obligations. The association, then, pays the recycling companies a fee for accepting the materials.

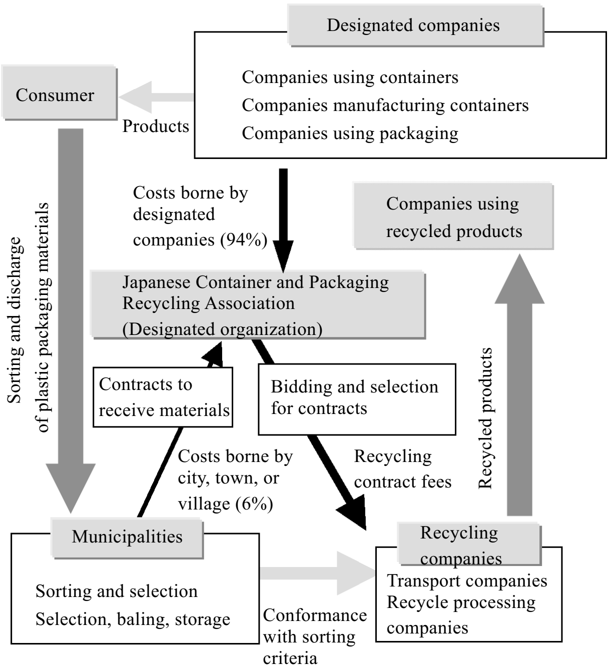

Fig. 3 Organizational structure for packaging waste recycling law

3.3 Recycling methods

When the Plastic Packaging Recycling Law was first introduced in 1995, the approved method of recycling plastic materials other than PET bottles did not include 'recycling of waste plastics in blast furnace system.' However as shown in **Table 1**, this method is now considered as chemical recycling as defined in 'Use As Raw Materials for Products' Clause 2. 8.1 of the Law.

Other methods of recycling now also include gasification (use of the gas consisting primarily of H_2 and CO as a chemical material and a fuel), and conversion into raw material for coke ovens (to produce coke, hydrocarbon oil, and gas consisting primarily of H_2 and CO). Conversion to fuel in cement kilns and RDF(Refuse Derived Fuel)used in thermal recycle operation is not approved as a recycling method.

3.4 Sorting criteria for plastics other than PET bottles

Sorting criteria for plastics other than PET bottles are shown in **Table 2**. At the municipality storage facility, there are several rules to proceed sorting. The materials should be coarsely sorted to reduce materials other than plastic packaging materials to a maximum of 10%. They should be, then, compressed using a baling machine in order to prevent scattering of the materials and to improve efficiency in transport, and sufficient material to fill a single 10 ton truck should be stored in a single location.

3.5 Pre-treatment plant for conversion to raw material for blast furnace[3)-5)]

The following must be considered when plastic packaging materials other than PET bottles are recycled.

(1) Processing of chlorine-contained plastics (e.g. PVC).

(2) Admixture of film and solid bottles.

(3) Admixture of food residue and impurities within containers.

The process of conversion of plastic packaging materials to raw material for blast furnace is complex. It is shown in **Fig. 4**.

Table 1 Recycling methods for plastic packaging

Classification		Recycling methods	Application
Raw materials	Material	Conversion of white expanded polystyrene to volume-reduced granules, ingots, and pellets.	Raw materials for expanded polystyrene trays and other plastic products.
		Pellets etc.	Raw materials for plastic products etc.
		Conversion to plastic products.	Plastic products
	Chemical	Conversion to reducing agents for blast furnaces.	Reducing agents for iron ore.
		Conversion to hydrocarbon oil.	Raw materials and fuel for chemical industries.
		Gasification (H_2 and CO)	Raw materials and fuel for chemical industries.
		Conversion to raw material for coke ovens.	Coke, hydrocarbon oil, and gaseous raw materials consisting primarily of H_2 and CO for coke ovens.

Table 2 Sorting criteria for all plastics other than PET bottles

Items	Sorting criteria	Operating guidelines
Storage units	* Generally collected in amounts suitable for transport by 10 ton truck.	* Maximum truck capacity not specified. * Picked up within two weeks of request from municipalities.
Storage format	* Compressed using balers etc. to reduce volume, and bundled for packaging to maintain shape and prevent scattering. * Shape and dimensions not specified, however a density of 0.25–0.35 t/m^3 is necessary to ensure that bales are easily broken up.	* Bottle tops removed before compression. * No smell. * Recommended dimensions: (1) 600 x 400 x 300, (2) 600 x 400 x 600, (3) 1000 x 1000 x 1000 * PP or PET straps desirable on bales.
Quality	* Following impurities not included or adhering - Other materials used in containers. - Materials other than containers. - PET bottles used for soft drinks, liquor and soy sauce. - Lids of non-plastic materials. - Food residue etc (washed or wiped). * Coarse sorting (visual inspection and removal of impurities) by local authority.	* Containers and packaging plastic exceeding 90%. * No metals, glass, or paper containers and packaging materials. * No plastic products other than containers and packaging (e.g. buckets, hand basins) * No impurities such as metals, glass, cloth, ceramics, food residue, organic waste, paper, leather, or rubber. * No dripping
White Styrofoam food trays	* Independent sorting and collection possible. * Washed and dried. * Does not include styrofoam cup noodle containers, take-home meal containers, or shock absorbing material. * Paper and film removed to ensure the material recycle	* Sealed in translucent polyethylene bags. * White trays (both sides) more than 90%. * No colored or patterned trays, or trays of different material (e.g. PE, PP, PET, non-foam PS). * No impurities such as metals, glass, cloth, ceramics, food residue, organic waste, paper, leather, or rubber

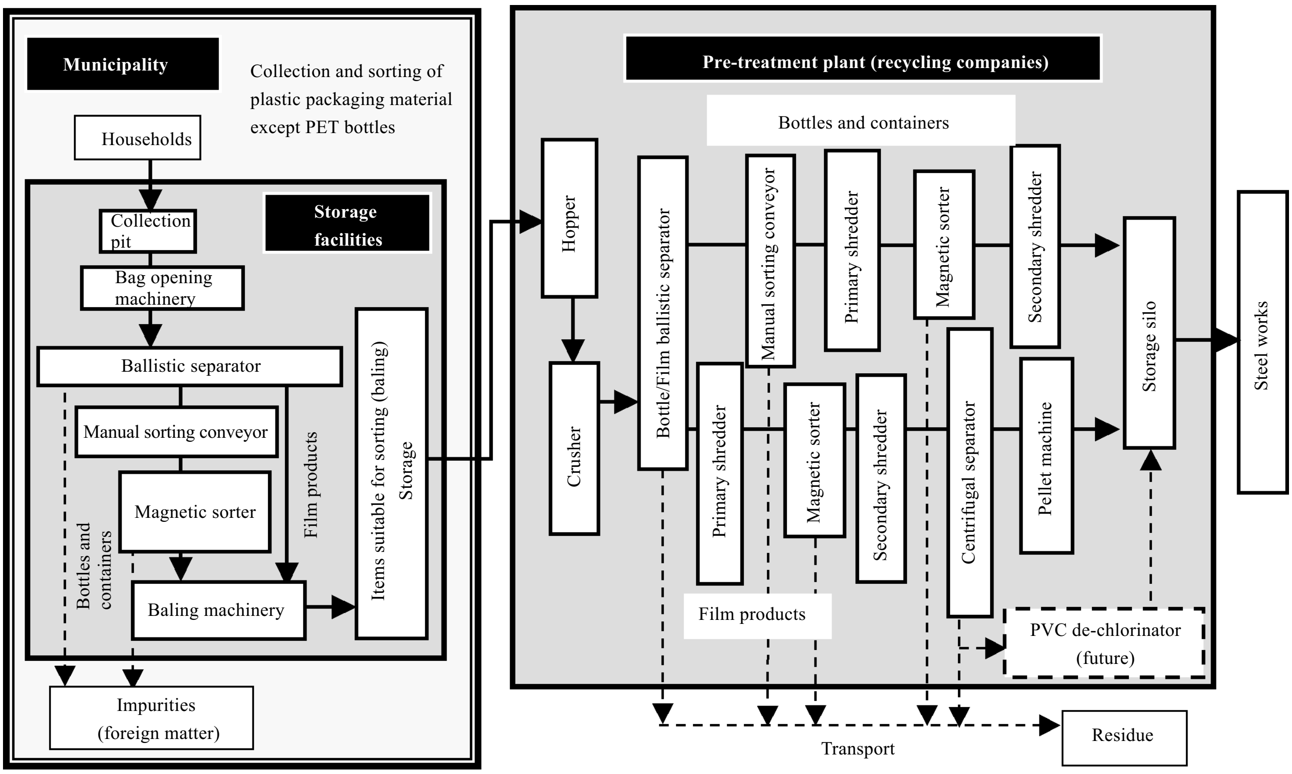

Fig. 4 Processing flow of recycling plastic packaging material except PET bottles for use as blast furnace material

Bag opening machinery is installed at the municipality storage facility to remove materials collected in plastic bags. After the bags are opened, bottles, cans, and paper, and plastics in the form of products other than containers, and Class 2 PET bottles, are removed. As plastics in the form of products other than containers may also be used as blast furnace reducing agents, a new system is desirable to take advantage of this material.

To simplify the removal of these impurities, a ballistic separator is used to sort heavier objects such as solid bottles and plastic containers, and light objects such as film and sheet on the basis of their weight. The heavier items are further sorted on the conveyor manually to remove impurities. These items are sorted and baled to satisfy the sorting criteria, however to simplify handling in the subsequent recycling equipment it is desirable that film and solid items be compressed and baled separately.

In the pre-treatment plant the bales are broken up and the material is once again passed through a ballistic separator to remove the remaining foreign matter. The solid items are passed to a manual-sorting conveyor where items unsuitable for recycling are removed, and following crushing to the required particle size, are used as blast furnace reducing agents.

After crushing film and sheet to the required particle size, the material is separated in a centrifugal specific gravity separator to remove PVC. When water is employed as the separating medium, all materials with a specific gravity greater than 1.0 (e.g. polystyrene, PET) are also removed with the PVC. As polystyrene and PET are primarily used in containers and bottles, they are sorted as heavier items in the initial ballistic separation stage. The polystylene of pdysty less and PET except foam material mixed in with the film is therefore comparatively small.

The film material from which PVC has been removed is formed into pellets of the required size using pellet machine, and used as blast furnace reducing agents. The removed PVC is processed as residue for the foreseeable future, however research is currently underway in cooperation with the relevant organizations to permit the eventual use of this PVC as a raw material for blast furnace .

4. Construction of pre-treatment plant for conversion to raw material for blast furnace

Full recycling of plastic packaging materials has been required since April 2000. In order to accommodate these requirements, construction of pre-treatment plant for plastic recycling to raw material for blast furnace with 30000 ton/year processing capability is currently underway at both the Keihin and Fukuyama steel plants (see **Photo 1**). If the benefits of improvements in industrial facilities are included, by the year 2000, it will be possible to use 100000 tons of waste plastic annually as a raw material for blast furnace.

The steel industry plans the use of 1 million tons of waste plastics annually as steel making raw material by 2010, and NKK has plans to upgrade existing facilities, and to construct new facilities, as appropriate for the collection and sorting operations of municipalities.

Photo 1 Pre-treatment plant in Fukuyama City

5. Conclusion

The technology for recycling of waste plastic to blast furnace reducing agents has the following advantages.

(1) Large scale and stable processing is possible.

(2) No dioxins are produced, and carbon dioxide emissions are reduced, with consequent benefits in terms of reducing the load on the global environment.

(3) Efficiency of use of resources is 80%, thus allowing reduced consumption, and more effective consumption, of fossil fuels.

In addition to recycling high-quality plastics (e.g. PET bottles), and making aggressive use of recycled products, it is important to develop a system for consumers to reduce the volume of plastic waste.

The use of waste plastic as a reducing agent of blast furnace both a socially and economically appropriate technology to handle the recycling of plastic materials not suitable for reuse.

Future changes in the constituents of plastic containers and packaging, and further development of sorting and recovery systems, will allow simplification of equipment, and further reduce total life cycle costs.

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