Recycling Technologies for Promoting Recycling-oriented Society

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NKK has developed a number of recycling technologies to recycle wastes as raw materials in iron and steel making processes. In response to the enactment of a series of recycling laws since 2000, NKK started new businesses of recycling waste plastics, used home electrical appliances, and waste PET bottles. Further, R&D on recycling construction and demolition debris and used motor vehicles is ongoing. This paper outlines the new businesses and technologies NKK has developed for recycling resources.

1. Introduction

Alongside efforts to prevent global warming by reducing CO_2 emissions, waste treatment has become widely recognized as an important issue for building a recycling-oriented society.

By effectively utilizing the synergistic effects of iron and steel making technology and engineering technology built up through its long history, NKK has been tackling issues related to conserving energy and resources as well as protecting the environment throughout the company. One good example is the conversion of the company's Keihin Works, which is located in the metropolitan area, into a steelworks that operates in harmony with the community and environment, and extensive research has been conducted on the possibility of recycling municipal wastes into useful resources. This paper outlines NKK's recycling businesses and technologies that make the best use of the iron and steel making processes of the steelworks.

2. Development of NKK's recycling businesses

2.1 Recycling Laws

The Law for Promotion of Effective Utilization of Resources was enacted in 1991 to promote the recycling of wastes as useful resources. The Law introduced the principle of extended producer responsibility, obligating producers to recycle end-of-life products. In June 2000, the Basic Law for Establishing a Recycling-oriented Society was enacted to promote the recycling of wastes as resources to solve problems related to wastes such as illegal dumping. The policy embodied in this Law is to prioritize the "reduction" and "reuse" of wastes, and maximize the "recycling" of wastes as materials (material recycling) or as energy sources (thermal recycling) before safe disposal.

The law that triggered NKK to enter the recycling businesses was the Containers and Packaging Recycling Law enacted in June 1995 and put into full force in April 2000.

As shown in **Fig.1**, in 1999, approximately 9.8 million tons of waste plastics were discharged in Japan including both municipal and industrial waste plastics, of which 33.3% or about 3.2 million tons were disposed of by land filling. Only 46% of the total or about 4.5 million tons were effectively used.

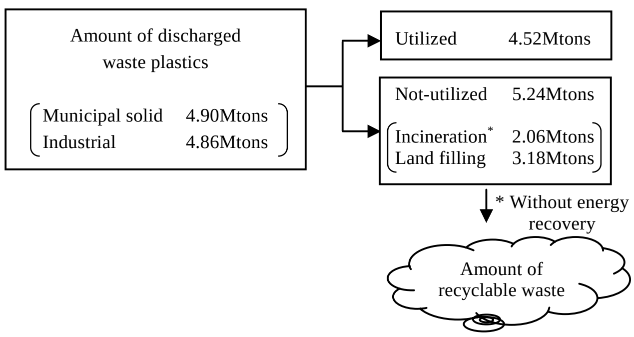

Fig.1 Amounts of waste plastics discharged in Japan
(1999 total : 9.76 million tons/year)

Fig.2 shows the ratio of waste containers and packaging contained in wastes discharged from Japanese households. Waste containers and packaging account for about 20% by weight, but more than 60% by volume. In particular, about 40% of wastes discharged from households is waste plastics. Therefore, recycling waste plastic containers and packaging as resources will significantly increase the ratio of waste plastics effectively used, and will greatly reduce the burden on municipal governments of treating wastes.

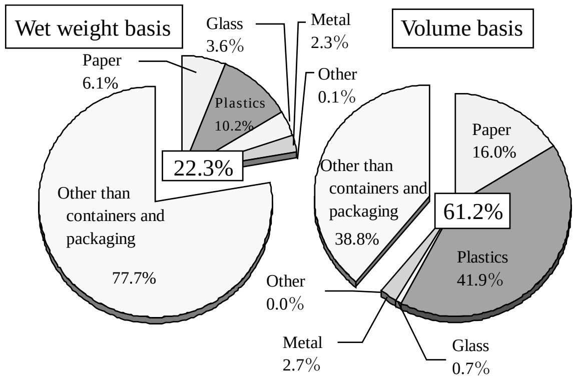

Fig.2 Ratio of waste containers and packaging in domestic wastes

2.2 Recycling of waste plastics

2.2.1 Recycling as blast furnace feed material (chemical recycling)

(1) Treatment of industrial waste plastics at Ohgishima

In an ironmaking blast furnace, coke is gasified into CO, and used for reducing iron ore (oxidized iron) into iron. Waste plastics can be used as the reducing agent in the blast furnace in place of coke. Waste plastics are pulverized and granulated, and then injected into the blast furnace through the tuyeres located near its bottom. Injected plastics are decomposed into CO and H_2, both of which act as reducing agents for converting iron ore into iron. As H_2 is used in the reducing reaction in addition to CO, approximately 30% less CO_2 is generated than when the blast furnace is operated solely by coke. About 60% of the plastics injected into the blast furnace are consumed for reducing the iron ore. The gas generated by the remaining 40% of the plastics is effectively used as fuels in other facilities in the steelworks such as power generating stations and blast ovens. However, waste plastics that contain chloride such as PVC (polyvinyl chloride) cannot be used in the blast furnace because hydrochloride generated from it is likely to corrode the blast furnace equipment.

Solid plastics such as plastic bottles are pulverized into designated sizes by the pulverizer and directly injected into the blast furnace. Film plastics are pulverized and granulated into designated sizes by the granulator before being injected into the blast furnace. PVCs contained in industrial waste plastics are removed before being shipped to the steelworks.

NKK started using waste plastics as blast furnace feed material in October 1996 at the No. 1 blast furnace located in the Ohgishima area of its Keihin Works using industrial waste plastics. NKK now uses about 50000 tons of industrial waste plastics as the reducing agent in the blast furnaces.

NKK currently has waste-plastic supply contracts with several hundred companies, including electrical-appliances makers, communication companies, automakers, machinery makers, chemical producers, printing companies, plastic processors, and supermarkets. A large proportion comes from the metropolitan area, but sources are now spread across the country from Hokkaido to Kyushu.

(2) Treatment of municipal waste plastics at Fukuyama and Mizue

Based on the requirements stipulated in the Containers and Packaging Recycling Law put into full force in April 2000, commercial recycling of waste plastic containers and packaging, which account for much of municipal waste plastics, was started.

In this recycling system, consumers are required to selectively discard waste plastic containers and packaging, which are then collected separately, sorted in accordance with designated sorting criteria, and stored by municipalities. Each municipality has a contract with the JCPRA (Japan Containers and Packaging Recycling Association) for collecting these stored items and recycling them into usable materials. Firms that manufacture or use containers and packaging in their business are called "specified business entities" under the Law, and bear most of the cost of operating this recycling system.

Chemical recycling methods designated under the Law include use as the reducing agent in blast furnaces, conversion into fuel oil, gasification, and use as coking material. **Fig.3** shows the flow for converting domestic waste plastics to blast furnace feed material.

Bales of waste plastics that arrive at the treatment site are first untied and placed in the ballistic separator for separating into solid plastics and film plastics. Solid plastics such as plastic bottles are then placed on the manual sorting line for removing impurities, and pulverized into designated sizes by the pulverizer, and injected into the blast furnace as the reducing agent.

Film plastics are pulverized into designated sizes by the pulverizer, and charged into the specific gravity separator for PVC removal by using the difference in specific gravity. After PVC removal, the pulverized film plastics are granulated into designated sizes by the granulator before being fed into the blast furnace.

In response to the Containers and Packaging Recycling Law enforced in April 2000, waste plastic recycling facilities with an annual capacity of 120000 tons were put into operation at NKK's Fukuyama Works (Hiroshima Prefecture) and the Mizue area of Keihin Works (Kawasaki City).

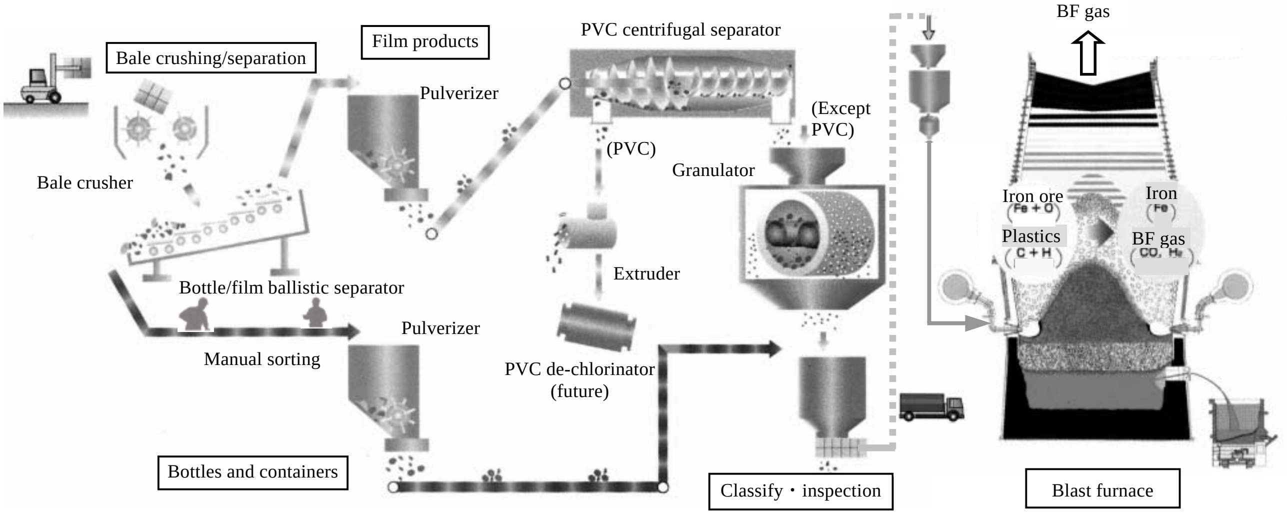

Fig.3 Schematic flow for converting domestic waste plastics to blast furnace material

2.2.2 Recycling of waste PET bottles

Based on the Containers and Packaging Recycling Law, several companies have already started the business of recycling waste PET bottles since 1997. PET bottles are widely used as containers for soft drinks, soy sauce, and alcoholic drinks. Domestic consumption of PET bottles in Japan is increasing each year and reached almost 400000 tons in 2001, of which about 170000 tons were collected by municipalities. The current collection ratio is 44%, far surpassing the 1997 ratio of 10%, and is expected to increase further in future.

The NKK Group constructed a waste PET bottles recycling plant with an annual capacity of 10000 tons at the Mizue area of Keihin Works, and commenced operations in April 2002.

The process flow of treating waste PET bottles at this plant is shown in **Fig.4**. This plant processes transparent waste PET bottles into PET resin flakes. Waste PET bottles collected by municipalities contain colored bottles, caps, and labels. The most important issue in this operation is how to remove these foreign objects efficiently and accurately. This plant employs a combination of mechanical sorting, manual sorting, automatic bottle sorting, and label and cap separation. The separated foreign objects are sent to the adjacent plant that recycles waste plastics into blast furnace feed material.

This plant recycles waste PET bottles into useful resources while generating almost no other wastes, thanks to its advantageous location in the steelworks.

In the past, recycled PET flakes were mainly used for producing fibers for cushion materials and heat-insulating materials, and plastic sheets. This plant employs alkali cleaning and produces PET flakes used for producing high-grade fibers.

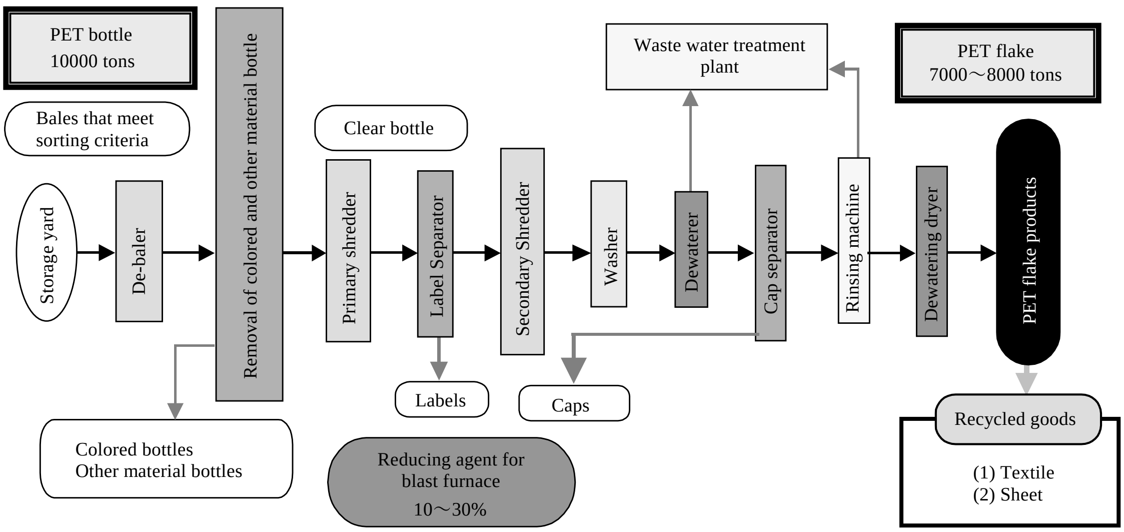

Fig.4 Schematic flow of the recycling facility for waste PET bottles

2.2.3 Waste containers and packaging pretreatment by PFI

The Containers and Packaging Recycling Law obligates each municipality to collect waste containers and packaging from households, and pretreat (sort, compress, bundle), and store them until delivery to recycling operators. Some municipalities have started to consign these pretreatment operations to private-sector companies under PFI (Private Finance Initiatives) for utilizing the management resources and know-how of the private sector.

The NKK Group is actively participating in these PFI projects. The Group has already been awarded contracts by Sendai City and Nagoya City, and has constructed facilities for sorting, compressing and bundling waste plastic containers and packaging. These facilities started operation in 2000.

2.3 Recycling of used electrical appliances

In April 2001, a new law mandating the recycling of designated home electrical appliances (Home Appliances Recycling Law) was enacted. In order to start a new business based on this Law, NKK established a new company jointly with Mitsui & Co., Ltd. and Sanyo Electric Co., Ltd. in August 2000, prior to the enactment of the Law.

The Home Appliances Recycling Law obligates manufacturers of home electrical appliances to recycle four designated used appliances: televisions, washing machines, air conditioners, and refrigerators. The manufacturers may carry out the obligatory recycling themselves, or must consign it other firms.

The new company constructed a recycling plant in the compound of NKK's Keihin Works and started operation in 2001. The plant can annually process 800000 units of the four designated types of home electrical appliances under contracts with the manufacturers of these appliances.

The material compositions of the four designated types of home electrical appliances are as shown in **Fig.5**. Except for televisions that have a high glass ratio, these appliances contain iron, plastics and nonferrous metals at the combined ratio of more than 80%. The recycling ratios designated by the Law are more than 55% for televisions, more than 50% for refrigerators and washing machines, and more than 60% for air conditioners. To achieve these recycling ratios, therefore, it is important to efficiently recover iron, plastics and nonferrous metals.

The equipment employed in this plant was designed for achieving a high recycling ratio for used home electrical appliances. **Fig.6** shows the flow of recycling these appliances, and also in what applications recovered materials are used. The plant is composed of the pre-sorting process (manual dismantling, etc.) and mechanical crushing & sorting process.

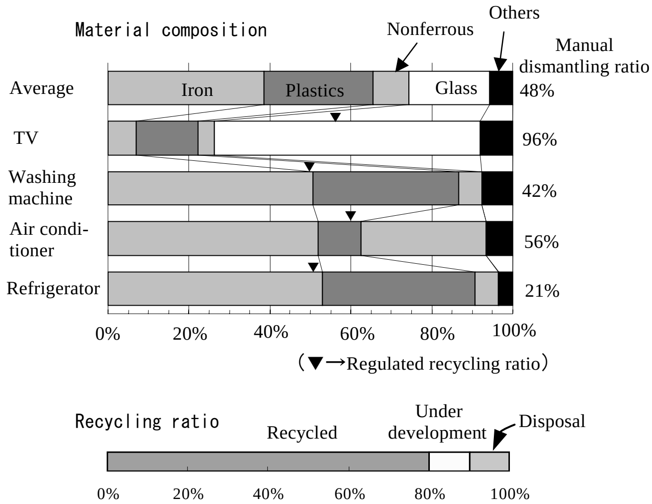

Fig.5 Material composition and recycling ratio of used home electrical appliances

Used appliances are delivered to the plant in cargo containers. In the manual dismantling area, they are taken out of the container by the manipulator, weighed, and placed on the work platform. Refrigerant fluorocarbon is recovered from refrigerators and air conditioners using the fluorocarbon recovery device. The mechanical crushing & sorting process is composed of the conventional crusher used for processing large wastes, wind sorting machine, magnetic sorting machine, nonferrous metal sorting machine, urethane compressing machine, and heat-insulating fluorocarbon recovery device.

In the used television processing yard, circuit boards and cables are recovered, and TV tubes are separated from housings. Housings made of plastics are utilized as blast furnace feed material. TV tubes are transported to a company which specializes in processing them into cullet, which is recycled into new TV tubes by TV tube makers.

In the presorting & crushing yard, three items other than televisions are manually dismantled. In manual dismantling of refrigerators and air conditioners, plastics are recovered as in televisions as well as refrigerant fluorocarbon. Washing machines undergo the same type of recovery process. In addition, brine is recovered from the brine ring attached at the top of the washing basin as a balance. The treatment of recovered brine is consigned to other companies.

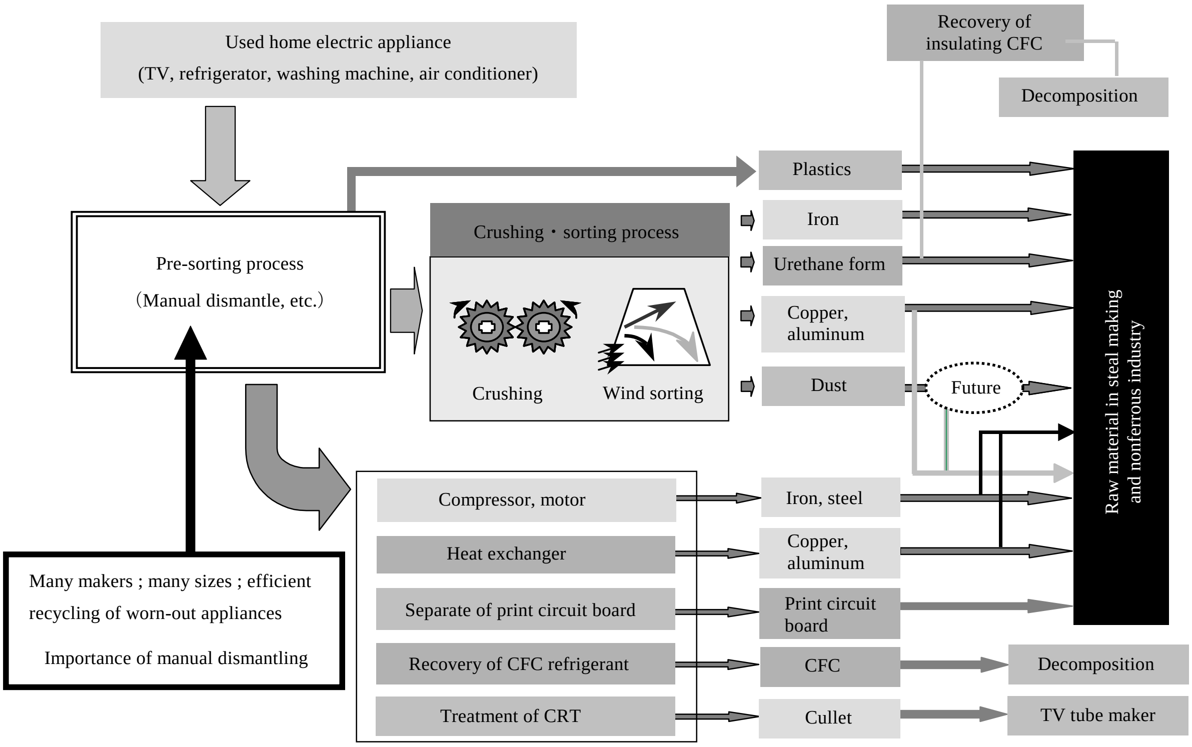

Fig.6 Schematic flow of recycling used home electrical appliances

After used appliances are manually dismantled and major component parts removed, the remaining parts are charged into the crusher and then mechanically sorted. Heat-insulating urethane in refrigerators is separated by wind sorting, compressed, and used as blast furnace feed material. Heat-insulating urethane contains fluorocarbon used as a foaming agent. In this plant, fluorocarbon released from the crushing and compressing processes is adsorbed by activated carbon in the foaming-agent recovery device, thus avoiding further damage to the ozone layer and global warming. Iron and nonferrous metals are recovered by the magnetic sorting machine and nonferrous sorting machine respectively, and used as iron and steel making materials.

A feature of this appliances recycling plant is that most of the recovered materials are effectively used in adjacent iron and steel making facilities. Its unique advantage is that the recovered plastics, which account for nearly 30% of home electrical appliances, are directly used in the blast furnace waste plastic feeding operation. As a result, the recycling ratio at this plant currently exceeds 80%. R&D is continuing, aiming at raising this recycling ratio to more than 90%.

3. Future recycling technologies toward establishing a recycling-oriented society

3.1 Expansion and upgrading of blast furnace feed technology

3.1.1 Blast furnace feeding of PVC by removing chlorine

In the current operation, unusable PVCs are separated and removed from waste plastics before feeding them into the blast furnace. If PVC could be used, almost all types of waste plastics could be turned into such feed material.

When PVCs are heat-treated at 300°C to 400°C in an atmosphere without oxygen, they are thermally decomposed and generate hydrochloride. If PVCs could be thermally decomposed and residual substances fed into a blast furnace, while recovering generated hydrochloride, 100% recycling could be achieved.

The technology for removing chlorine by thermal decomposition is completely different between when the content of PVCs in mixed plastics is in a low range of approximately 2% to 30%, and when the plastic is solely composed of PVCs or contains more than 50%.

When the PVC content is low, the thermally decomposed substance has sufficient fluidity that thermal decomposition can be carried out in a reaction vessel while agitating and moving forward the plastics by screws or paddles. The thermally decomposed substance can be fed into a blast furnace after being cooled and granulated. Hydrochloride is generated at a comparatively low concentration, and will be treated by neutralization.

When the plastic is solely composed of PVCs or contains more than 50%, the thermally decomposed substance does not have sufficient fluidity and so thermal decomposition needs to be carried out in an externally heated rotary kiln while agitating and mixing with a certain medium. The thermally decomposed substance will be fed into a blast furnace after being cooled and pulverized. A candidate medium is powder coke used as a material in a steelworks. Powder coke is used to prevent thermally decomposed substances from agglomerating in the kiln and adhering to the inner wall. Hydrochloride generated by thermal decomposition will be absorbed by water in an absorption tower, refined by distillation, and recovered as hydrochloric acid.

Jointly with the Plastic Waste Management Institute and Vinyl Environmental Council, NKK constructed a 5000ton/year plant for conducting experiments on the technology for de-chlorinating high-concentration PVCs, and started test operation in 1999, through which its technological feasibility was almost verified. The process flow is shown in **Fig.7**.

3.1.2 Wood chip blast furnace feeding

The Construction Material Recycling Law stipulates that the ratio of recycling construction waste wood must be raised from the current 40% to 95% by 2010. The major constituent of waste wood is carbon as in coal, and so its use as a reducing agent in a blast furnace will significantly contribute to achieving this target recycling ratio.

Photo 1 shows the test plant for wood chip blast furnace feeding. Waste wood delivered to the plant is coarsely crushed, nails and metal fittings are removed by the magnetic sorting machine, then the wood is further crushed into wood chips of designated sizes, which can be injected into a blast furnace in a similar manner to plastics and used as a reducing agent. Development and verification tests of this technology are under way.

Photo 1 Test plant for wood chip blast furnace feeding

3.2 Shredder dust treatment by heat medium bath

Shredder dust generated in treating used motor vehicles and home electrical appliances is a serious problem. This dust contains materials from PVC-covered electric wires and halogen-based fire-resistant plastics, and is mostly disposed of by landfilling.

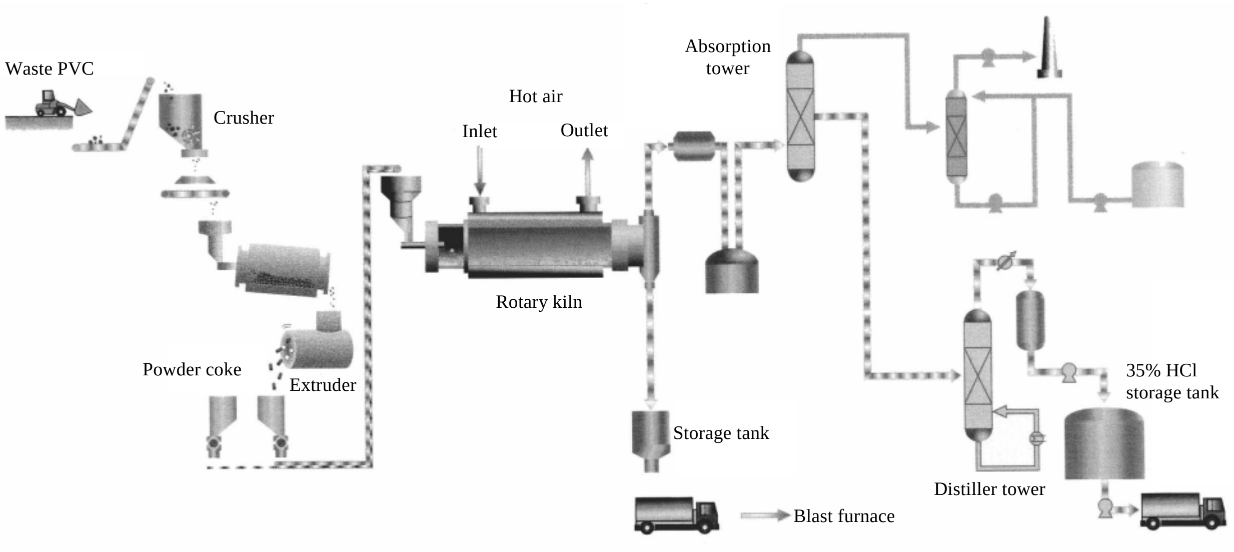

Fig.7 Schematic flow of PVC recycling with rotary kiln

In order to solve the problem, NKK has developed an innovative system for recycling shredder dust as shown in **Fig.8**. In this process, shredder dust is quickly separated into plastics, metals, and inorganic substances by dissolving it in a coal-tar-based heat medium bath heated to around 300°C.

Plastics such as polyethylene and polypropylene float up to the surface of the heat medium bath. They are recovered, granulated into designated sizes, and used as a reducing agent in a blast furnace. PVCs and halogen-containing plastics are thermally decomposed, and their halogen contents are removed. The decomposed substances also float up to the surface, are recovered, and used as a reducing agent. Urethane is degassed by thermal decomposition, compressed, and used as a reducing agent as well.

On the other hand, iron and copper sink to the bottom of the bath along with glass and sand, and are recovered as deposit, from which iron and copper are separated for use as recycled resources for iron and steel making and other purposes.

The heat medium method is expected to boost the motor vehicle recycling ratio to more than 95%.

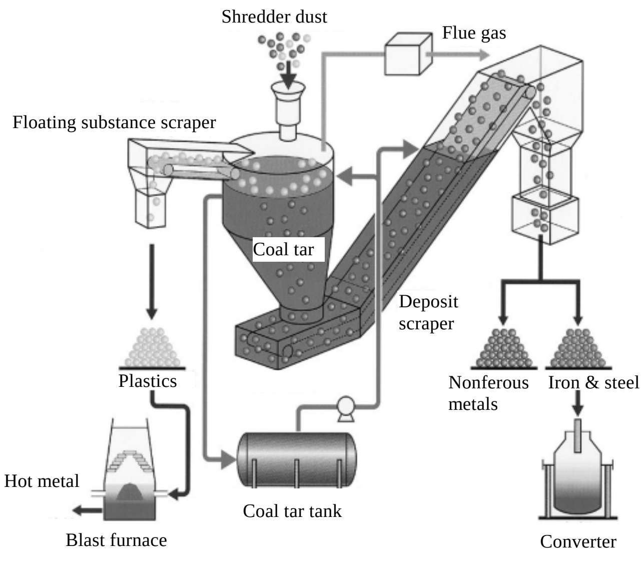

Fig.8 Heat medium bath for treating shredder dust

3.3 Recycling of construction and demolition debris and used motor vehicles

As stated before, R&D on using construction waste wood as blast furnace feed material is ongoing. In addition, the gasifying and melting furnace is expected to play an important role in recycling construction and demolition debris. This type of furnace can turn the non-combustible components in the construction and demolition debris into molten slag and metal, and combustible components into gaseous fuel.

Yet another new law, the Motor Vehicles Recycling Law, is planned to be enacted in 2004. The Law requires that the motor vehicle recycling ratio be raised to 95% and the ratio of shredder dust disposed of by landfilling be reduced to less than 1/5 by 2015. This goal cannot be achieved without widespread application of the gasifying and melting furnace and heat medium method, and so expectations are high for the gasifying and melting furnace.

4. Conclusion

NKK's business development and R&D activities on resource recycling were outlined. NKK's recycling businesses are making the best use of the advantage of its steel works located in the urban area where huge amounts of industrial and municipal wastes are generated, thus providing the urban steelworks with new social value. Existing facilities are being effectively used to turn wastes into iron and steel making materials. In future, in response to the enactment of a new series of laws that mandate the recycling of wastes such as construction and demolition debris, used motor vehicles, and waste foods, NKK will continue to conduct R&D and set up businesses for helping to build a recycling-oriented society.