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Some Problems of Recycling Industrial Materials

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Abstract: The industrial system should learn from the natural ecosystem. The resource utilization efficiency should be increased and the environmental load should be decreased, depending on the materials recycled in the system. The classification of industrial materials from the viewpoint of large-scale recycling was stated. Recycling of materials, on three different levels, was introduced in the industrial system. The metal flow diagram in the life cycle of products, in the case of no materials recycled, materials partially recycled, and materials completely recycled, was given. The natural resource conservation and the waste emission reduction were analyzed under the condition of materials completely recycled. The expressions for the relation between resource efficiency and material recycling rate, and the relation between eco-efficiency and material recycling rate were derived, and the curves describing the relationship between them were protracted. The diagram of iron flow in the life cycle of iron and steel products in China, in 2001, was given, and the iron resource efficiency, material recycling rate, and iron eco-efficiency were analyzed. The variation of iron resource efficiency with the material recycling rate was analyzed for two different production ratios.

Key words: recycling; industrial material; product life cycle; resource efficiency; eco-efficiency; material recycling rate

The ecological problems of the industrial system must be studied by imitating the ecosystem in nature (see Fig. 1), which is a crude example of sustainable development. The components in the ecosystem depend on and influence each other, and constitute a close cycle of materials. The whole ecosystem neither takes any resources from the nature nor emits any wastes to the nature, and can operate continually relying on only solar energy. If a manmade system can constitute a close cycle of materials similar to the ecosystem in nature, it will undoubtedly be sustainable. However, it is impossible for an industrial system to achieve this goal. It will be better if it can take fewer resources (this includes energies) from nature, and simultaneously increase the output of products and wealth, depending on the materials recycled in the system. Recycling of materials is the basic measure of increasing resource efficiency and decreasing environmental load.

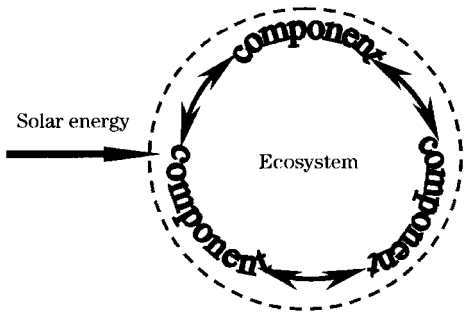

Fig. 1 Ecosystem in the nature

After coming into the industrial system, natural resources flow in the following stages: production, fabrication, manufacture of products, and products used by customers. When the products become obsolete, some materials in the obsolete products are reclaimed and returned to the industrial system as raw materials, and the others are not reclaimed, and are emitted into the environment as wastes and contaminants[1].

The recycling of industrial materials is contributing to conservation of natural resources and environment improvement. However, it is a pity that

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only a small part among them is recycled. The metal recycling level is not high, although it is easier to regenerate. About 50% of them are emitted into environment even in developed countries. The recycling rate of several metals in Japan and Canada is shown in Table 1[2].

It must be pointed out that only a part of the materials contained in industrial products can be recovered and recycled. In this respect, industrial materials are classified into three groups, as follows[3]: (1) materials economically and technologically compatible with recycling under the present prices and regulations, such as most structural metals, industrial catalysts, paper, glasses, and some kinds of plastics; (2) materials economically not compatible with recycling, but technically feasible, such as some structural and packing materials, most refrigerants, and solvents; (3) materials for which recycling is inherently not feasible, including coatings, pigments, pesticides, herbicides, preservatives, explosives, detergents, fertilizers, fuels, and other chemical products.

Therefore, the contents in this article are fit for the materials in group one and two. More materials may become suitable for recycling with the development of technology.

Theoretical study on the recycling of industrial materials should be based on the life cycle of the products. Some essential principles of material recycling are obtained from studying the quantitative relationships among each substance flow. Here, the products are designated to an element or a steady compound; furthermore, the life span of products from production to obsolescence and the variation of product output with time are considered.

Table 1 Recycling rate of several metals in Japan and Canada

	Al	Cu	Zn	Pb	Cd	Fe
Japan	54%	66%	20%	66%	28%	—
Canada	32%	43%	19%	55%	—	45%

1 Three Scales of Recycling Industrial Materials

In the industrial system, there are three kinds of recycling flows of materials[4].

(1) Small-scale recycling—recycling of materials within an enterprise. For instance, the wastes of downstream unit processes return back to upstream unit processes for retreatment, such as water recycling in an enterprise, other expendables, byproducts, and so on, recycled in an enterprise.

(2) Middle-scale recycling—recycling of materials among different industrial sectors. For instance, the wastes of downstream industrial sectors return back to upstream sectors for retreatment, or wastes of one of the industrial sectors go to another sector for utilization.

(3) Large-scale recycling—when the industrial products become obsolete after their use, some materials containing the obsolete products are returned to the original industrial sectors to be used as raw material. These three kinds of recycling are beneficial in increasing resource efficiency. It is true that large-scale recycling is the most efficient way to increase resource efficiency in the case of a constant volume of economy. Nevertheless, in China, for the sake of rapid growth of its economy, the situation is quite different. It seems that the material recycling on three scales is of equal importance in the case of China.

Reduce is in the first place in an enterprise or between enterprises. That is to say that reducing the generation of wastes and natural resource consumption should be first paid attention to. Recycling of wastes comes second. Besides this, reuse must come prior to recycling. That is to say, products should be first reused after their first use stage and the use life span of products should be extended. In addition, it should be pointed out that the priority order of 3R (reduce, reuse, recycling) should be kept in mind during the process of developing circular economy. This is extremely important for China, because there is still a lot of study to do on reduce and reuse.

2 Diagram of Metal Flow in Life Cycle of Products

A simplified model of metal flow in the life cycle of products without metal recycling is shown in Fig. 2[5]. The import and export of metal scraps and products are not taken into consideration in the model. All the flow rates indicated in Fig. 2 are not those of materials in kind; instead, they are the flow rates of iron contained in the flowing materials. The year of interest is designated as the year τ, when the annual output of the metal of the nation is $(1+b)P_\tau$ t/a, and cP_τ t/a represents the losses by means of metal wastage during the production stage. The output of metal products is P_τ t/a, and bP_τ t/a of metal scraps are generated in the manufacturing stage. The span of a product life cycle is assumed to be $\Delta\tau$ years. The