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Fusion technology of artifacts considering environmental recycling for sustainability

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Abstract: Recently, the recycled amount of electric, mechanical parts, and appliances in artifacts has increased. These products use valuable rare metals such as platinum group metals and gold, which are included occasionally as additives. Rare metals are maldistributed in the world and most of them are produced in small quantities. A small amount of rare metals used in the appliances causes a large loss of rare metal resources because of the lack of an economically recycling method. The present recycling technologies including physical and chemical separation methods that are considered for recycling of electric, mechanical parts and appliances.

1. Introduction

One of the main events related to recycling technology is the East Asian Resource Recycling Symposium that has been held 7 times including this year. Fig. 1 depicts the percentage of research topics in all meetings, since 1997. A look at Fig. 1 shows that interest in recycling subjects such as recycling of electrical and mechanical parts is increasing. Moreover, TMS, an American professional society, and other European societies are also holding similar symposiums on recycling. REWAS, a global symposium on recycling, waste treatment and clean technology gather researcher from Asia, USA and EU. The first meeting of REWAS was held in 1999 and 2nd congress scheduled for 2004.

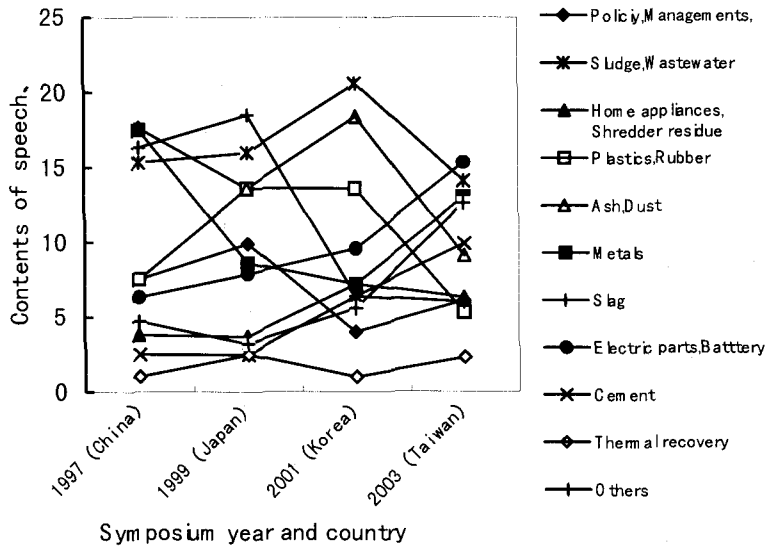

Fig. 1. Research topics in East Asian Resources Recycling Technology Symposium.

2. Flow of artifacts

2.1 Three types of artifacts

A: Artifacts supplying service

They can be supplied in each family as rental-lease system. They need to be maintained and upgraded. Then, the recycling process, which is not necessary to be accomplished for individual items, is carried out. The producers have the main responsibility for recycling.
Example: refrigerator, air conditioner, copy machine, heating tools, game machine, fluorescent lamp, battery etc.

B: Artifacts for individual possession

They are produced as tailor-made for individual consumption. It is difficult to include them in the rental-lease system. Individual consumers have the main responsibility for recycling.
Example: clothes, medical drugs, cosmetics, shoes, notebook, cooked foods, sleeping goods, writing tools, private house, glass tools, personal ornaments etc.

C: Artifacts between A and B

Both the producers and the consumers have responsibility for recycling.
Example: automobile, personal computer, mobile phone, robots, furniture, CD player, cleaner, washing machine, etc.

2.2 Quantity analysis of materials for constructing artifacts

2.2.1 Demand, resource quantity and resource amount change

2.2.2 Energy exhaustion and CO_2 emission for producing artifacts

2.2.3 Toxicity of used materials in artifacts

2.3 Design based on the material investigation

Materials quantity to produce artifacts; Recycling method; Collecting method of used artifacts; Feasibility of composition and decomposition.

2.4 Production of artifacts or parts

Minimum usage of materials for production; Long-life design of products; Low environmental impacts; Easy handling for production.

2.5 Sales and utilization

Low maintenance and repairing cost, Easy upgrade, Reuse of artifacts and parts, Optimum recycling method and low effects to environment, Estimation of quantities to judge the reuse and recycling

2.6 Collection method and cost

Tendering of used materials, Distance, Transportation judgement on land or sea

2.7 Recycling versus harmless treatment of materials

Energy consumption and environmental effects in crushing and grinding, separation, leaching and incineration technologies
Cooperation of local self-governing bodies, waste treatment companies and producers
Comparison between combustion and meltdown,
Utilization of smelter, cement industry and chemical plant

2.8 Judgement on re-utilization of artifacts and final disposal of used ones

It is desirable to change the non-toxic inorganic materials to soil and gravels and the salts to dissolve in the sea. On the other hand, microorganisms and decompose organic materials to be transformed to fertilizer.

3. Recycling of artifacts from a technological point of view

Finally, the used artifacts go to the recycling process. The optimum recycling technology should be employed in the process.

3.1 Mechanical decomposition of large amount of wastes

The purpose of decomposition is the liberation of each material from the used artifacts. The low energy consumption is desirable. The decomposition forces are pressure, shock, shear, repulsion, heating, plasma by large current, shock wave, etc.

The conventional crushing by means of shredder, etc. is used to crush automobile and vending machines. The fragmentation of plastics from metal plate in mobile phone can be performed by explosive in water. Also fragmentation of conductive material from dielectric one in liquid crystal display, and removal of nails from wooden timber can be carried out by electric disintegration. The crushing by hummer mill in liquid nitrogen is used for wasted tire and plastic materials, etc.

3.2 Separation of solid particles after mechanical decomposition

During the separation the energy is used while the entropy S_1 is discharged outside. The purity of separated material (1) increases, therefore, the entropy S^*_1 of material (1) decreases. The perfect separations are impossible by actual separation techniques for powder mixture. Thus, uncollected powders (1) are transformed as waste materials or environmental polluters. The entropy Sw_1 of uncollected materials increases. The techniques employed for solid separation are gravity, centrifugal, electromagnetic, while the separation is usually performed in an air or a liquid as a medium. The dry separation does not use liquid, therefore, it is economically convenient, since the wastewater treatment is not necessary. The dry separation is useful for particles larger than 75 μm in sizes.

The dry separation methods are follows,

Hand sorting
Pneumatic (air) separation: air table, zigzag air separator
Sieving
Shape separation
Collar sorting
Magnetic separation
Electrostatic separation
Triboelectrostatic separation
Eddy current separation
IR, fluorescent, X-ray, radioactive sorting

The wet separation using water or other liquid as medium is effective to separate particles smaller than 75 μm in size. The wet separation methods are as follows,

Gravity separation
Heavy dense medium separation
Sink-float separation using magnetic fluid or other liquid
Wet-magnetic separation
Liquid-liquid separation

The separated products by wet method are washed, followed by thickening, filtration, dewatering, drying and sometimes pelletizing.

3.3 Treatment of separated products

When the separated solid lump or powders becomes wastes, they are reduced in volume by incineration, etc. However, when the separated materials are valuable, they are treated chemically or biologically in the molecular and atomic state.

The chemical methods are divided in dry and wet methods as follows,

Dry method: Roasting, Heating, Thermal decomposition, Meltdown, Volatilisation, Heating in non-oxidizing atmosphere, Distillation

Wet method: Leaching, Dissolution, Sedimentation, Solvent extraction, Electro winning, Decomposition in supersaturated water, Reduction and oxidation

Biological wet treatment: Methane fermentation, decomposition in air atmosphere

The separated solid or powders (1) are further purified by chemical and biological reactions. They are used to compose the parts of artifacts. The chemical reaction uses energy, while entropy S_2 is exhausted to outside. The entropy S^*_2 of material can be reduced by purifying. It is impossible to recover 100% of materials and the remainder goes to outside as diluted materials or wastes. The entropy Sw_2 of diluted material increases. Thus, $S_2 > S_1$ and $Sw_2 > Sw_1$, $S_2 + Sw_2$ is larger than $S_1 + Sw_1$. As the purity of material increases, the larger entropy goes outside. Subsequently, the almost complete utilization in the case of zero emission of materials and the utilization by separations are compared by lifecycle assessment.

4. LCA compares treatment methods for wasted artifacts

Recently the recycling of wasted artifacts such as electric and machine parts is increasing. Following, different processes to recycle Ni tip capacitor are compared. In the solid separation of capacitor, the crushing and magnetic separation is employed. When Ni concentrate is recovered by a pyro-metallurgical process, the diluted Ni and $BaTiO_3$ are discarded (case A). On the other hand, both concentrates of Ni and $BaTiO_3$ are recovered by hydrometallurgical process and electro winning almost perfectly (Case B). The last considered case C is that all materials are discarded in the landfill. The LCA results for recovering process of Ni tip capacitor are listed in Table 1 (Shibayama, A. et al., 2002). According to LCA, environmental effects is almost perfect, when Ni and $BaTiO_3$ are recovered rather than discharged as wastes. This result shows that the solid separation is important after mechanical decomposition, while the almost zero emission of Ni and $BaTiO_3$ wastes causes more loads to environmental.

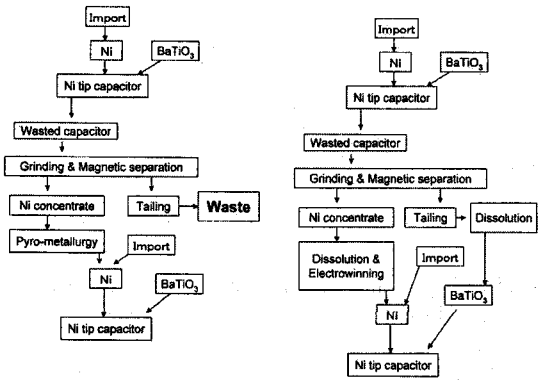

Fig.2. LCA flowsheet processes: A (waste are discarded) and B (most materials are recycled).

Table 1. LCA results for recovering processes of Ni tip capacitor.

	A Wastes	B Circulation	C All discarded
Energy consumption	3903	5136	2191
Consumption of minerals	10727	11209	15637
Greenhouse effect	510320	510334	510153
Acid precipitate	4303	4302	4303
Water pollution	397	398	397
Air pollution	39776	39774	39769
Total amount	569429	571150	572449

5. Recovery and diluted element in artifacts

Many catalysts are used in artifacts, however, the used amount is very limited. For instance, the catalyst to clear the gas exhausted from automobile are less than 0.1% of platinum group metal (Pt, Pd, Rd) on the honeycomb structure of cordierite ceramics. Also types of fuel cells, which use electrode containing Pt catalyst, are increasing. The design for long life in catalyst use and the maintenance of parts containing catalyst is important. At the end, parts using catalyst have to be recycled. Nowadays the diluted metals of Pt group are directly fed into furnace and recovered in the melted copper. In the future the recycling efficiency of Pt group metal will be increased if the μm order sizes of metal can be concentrated by the solid separation. The production of Pt and Pd is shown in Fig. 3. The largest 3 producers of Pt are South Africa (71.8 %), Russia (20.8 %) and North America (5.4 %) that produce 98 % of the world total production. Moreover, the main 3 countries responsible for Pd production are Russia (66.8 %), South Africa (23.9 %) and North America (1.2 %) that produce 92 % of the world total production. The design to be used for those maldistributed metals and short life term materials has to especially consider the easy recycling system. The recent supply and demand for Au in Japan are shown in Fig. 4. The domestic production is 48 % and remains constant. The gold demand for production of the electric and mechanical parts is increasing and reaches to more than 30% in 2002. Even if the recycled gold is increased to about 6% in these 3 years, the recycled gold percentage is quite low. Most of industrial gold is discarded as a diluted waste. The relationship between grade and recovery (Dalmijin et al., 2003) is shown in Fig. 5. If recovery is increased, the grade is decreased; therefore, it is impossible to recover 100 % of material. Now the design for electric and mechanical parts for gold recycling by environmental friendly leaching method is become more important. For example, the parts using layered plating gold should be decomposed easily for leaching method recycling.

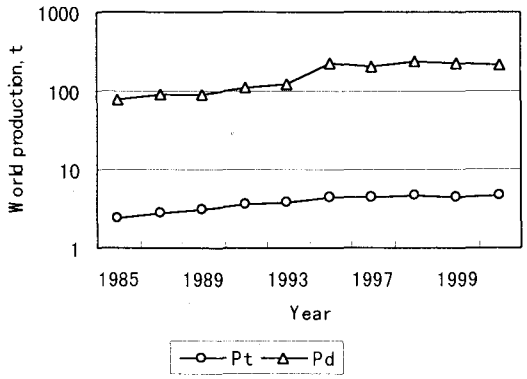

Fig.3. Total world production of Pt, Pd by year.

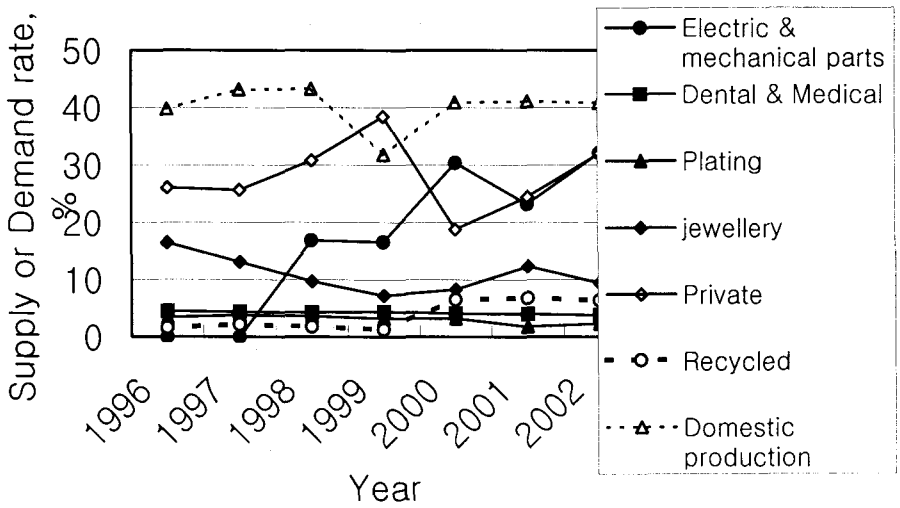

Fig. 4 . Gold supply and demand rate change per year.

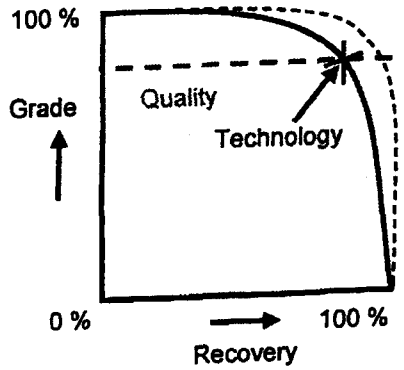

Fig. 5. Grade and recovery relationship.

6. Contradiction in regulation of hazardous substances

In Europe, for example, there ore restrictions on using certain hazardous substances such as Hg, Pb, Cr^{6+}, Cd in operated. Actually, in Japan Hg is used in fluorescent lump, however, the Hg hazard can be prevented if a controlling system is established. The new technology for separating the fluorescent powders mixture of μm order size is developed and the recycling method shows in Fig. 6. Earlier, it was impossible to recycle those powders economically. The new developed technology presents a new recycling system. Moreover, batteries using lead are economical and widely used. If the collected system for battery is constructed, it will results in an environmental friendly artifacts. The elements of Hg, Cd, Pb that exists as mainly sulphide minerals in the earth and those ions flows to the earth surface after oxidation. In Japan, many waste mine drainages from old mines including these ions are exhausted and they are neutralized and changes to non-toxic water. Sometimes the sever regulation are imposed due to an increase in CO_2 emission. Even if we produce new artifacts using exchangeable elements, we have to reduce the use of shorter life elements. When we produce and utilize the artifacts by using any elements. Some parts of used elements always discarded in a stage of diluted wastes and are spread to the earth surface. The entropy of wasted shorts the life of elements, thus, the useful resources are gradually reduces.

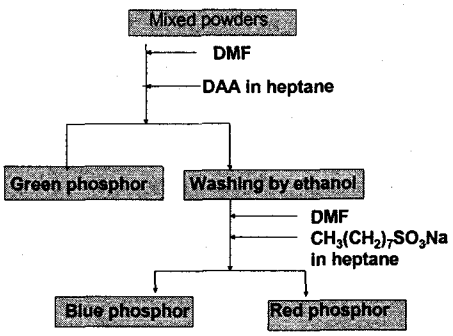

Fig. 6. Flowsheet for separation of fluorescent powders.

7. Concluding remarks

In the viewpoint of artifacts lifecycle, the environmental fusion technologies are investigated considering social system, material separation technology, datum of resources and technological innovation. In order to establish the sustainability, the limited resources have to be reused preventing the discharge in the diluted state. Therefore, it is necessary and important to develop new systems for collecting process, easily decomposition and configuration process, limitation of utilization and the combination of recycling technologies.

References

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