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Assessment of environmental risk and waste treatment technology

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Abstract

Environmental risk assessment for hazardous waste and the development of its appropriate treatment technology are very important issues for waste management in the 21 century. Here, we define a new concept "Rescue Number" (RN), which is proposed by ResCWE, Nagoya University for a management of the waste difficult to process (DTP waste). RN consists of the following two assessment indices. Risks of the industrial and municipal wastes for both human life and the global environment are assessed by the "Figure of Treatment Priority (FTP)". Recycling technologies of such DTP wastes are assessed by using the "Figure of Unprocessibility for Waste (FUW)", the concept of which is also defined by ResCWE in combination with FTP. The two indices are related to RN by the equation, (RN) = (FTP) × (FUW). Qualitative case studies on the assessment of various ceramic wastes are performed using the above concepts RN, FTP and FUW.

1 Introduction

A large amount of industrial and municipal wastes is discharged in the manufacturing process and after the public or household uses. Some of the wastes are hazardous when they are incorporated in human body as stable solids or dissoluble heavy metallic ions. Other wastes impose much environmental burden on ecology and the circulation system of air, water or soils of the earth. Precious or rare metals are also included in these wastes that are hopefully recycled for saving natural resources. Risk assessment of industrial and municipal wastes influencing on both human life and the global environment was attempted in terms of the "Figure of Treatment Priority (FTP)", the new concept

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of which was proposed by ResCWE, Nagoya University for the management of wastes difficult to process (DTP wastes) [1]. Recycling possibility of such DTP wastes was evaluated by using the "Figure of Unprocessibility for Waste (FUW)", the concept of which was also defined by ResCWE in combination with FTP. In the present paper, the principal concepts of FTP and FUW are introduced and formulated, and a new assessment system for waste management using "Rescue Number (RN)" is developed. Typical treatment examples to reduce the FTP and the FUW of industrial ceramic wastes are described in relation to various types of treatment technologies [2].

2 Risk assessment of wastes by FTP

Table 1 shows the influencing parameters for FTP of DTP wastes which include two risk categories, *i.e.*, (A) the risk group caused by the hazardous or toxic chemical substances for human life and the ecological system of animals and plants, and (B) the risk group arising from the environmental loads by various kinds of pollutants (CO_2, SO_x, NO_x, flons, ect.), energy consumption in the manufacturing process of products, and the depletion of natural resource or landfill site. These two kinds of risks are dependent on (C) the existent amounts and exposed states of these wastes, which are closely related to the social requirement for waste management. Therefore, each risk group, (A_i) or (B_j) by material i (hazardous chemicals included in A) or j (impact chemicals included in B) should be multiplied by the last factors (C_k) as a weighting coefficient of the item k, respectively, to formulate the FTP by a linear combination of the two risk groups.

$$(\text{FTP}) = \Sigma(A_i C_{Ak}) + \Sigma(B_j C_{Bk}) \quad (1)$$

The risk group A is related to the risks for all lives in short-range and short-term, while the risk group B to the risks for the global environment in long-range

Table 1. Influencing factors for FTP.

Parameter	Annotation
A	Direct hazards and toxicity for human life, animals and plants by chemical substances.
B	(1) Environmental loads by global pollutants (CO_2, SO_x, NO_x, frons, etc.). (2) Energy consumption in production process. (3) Depletion of natural resource. (4) Depletion of landfill site.
C	Weighting parameters such as: (1) Exposed state of waste. (2) Total amount of emission. (3) Local concentration of pollutants. (4) Legal regulations (international, domestic or local). (5) Demand from inhabitants.

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and long-term. In some cases, the separation of one risk event into A or B is rather difficult, *e.g.* in case of the pollutions arising from various dioxins. It is important, however, to pick up all the risks caused by the DTP wastes and to allot them into respective risk groups. Since a risk is generally formulated as a product of hazard and its exposure probability, the weighting coefficient C_k in eqn (1) is considered to include a kind of probability factor for the risk event A or B. As far as the environmental risk by hazardous wastes, however, a quantitative estimation of such weighting factors is difficult to fulfill on account of the complicate procedure to normalize the coefficients among different kinds of risk events. The final decision of the C factor should be made by considering the legal regulations or the social demands from inhabitants.

3 Assessment of waste treatment technology by FUW

Table 2 shows the influencing parameters for FUW, which consists of two unprocessibility groups, *i.e.*, (L) the thermodynamic and kinetic difficulty for recycling and (M) the difficulty in physical treatment, collection, separation and extraction of each component from the DTP waste. These two factors should be multiplied also by (N) the weighting coefficient of the item k such as the energy required for the waste treatment, the emission amount of hazardous gases/effluents accompanied by the treatment, or the usefulness of recycled product. Therefore, the FUW is formulated as

$$(\mathrm{FUW}) = \Sigma(LN_{Lk}) + \Sigma(MN_{Mk}). \qquad (2)$$

It is important in the assessment of waste treatment to criticize whether the recycling technology brings about another environmental pollutions (for air, water and soils) or energy loss by the waste treatment. From the viewpoint of the product, whether the products after the treatment are effectively utilized in cases of materials closed recycling or cascade recycling should be considered.

The material flow and energy flow in waste treatment process are illustrated in Figure 1. This is a possible diagram of the input and output of materials and

Table 2. Influencing factors for FUW.

Parameter	Annotation
L	Thermodynamic and kinetic difficulty in recycling treatment.
M	(1) Difficulty in physical or mechanical treatment. (2) Difficulty in collection, separation or transportation of waste.
N	Weighting parameters such as: (1) Energy required for waste treatment. (2) Output energy recycling (*e.g.*, thermal recycling). (3) Environmental loads by the waste treatment. (4) FTP of the treated products. (5) Usefulness of the treated product.

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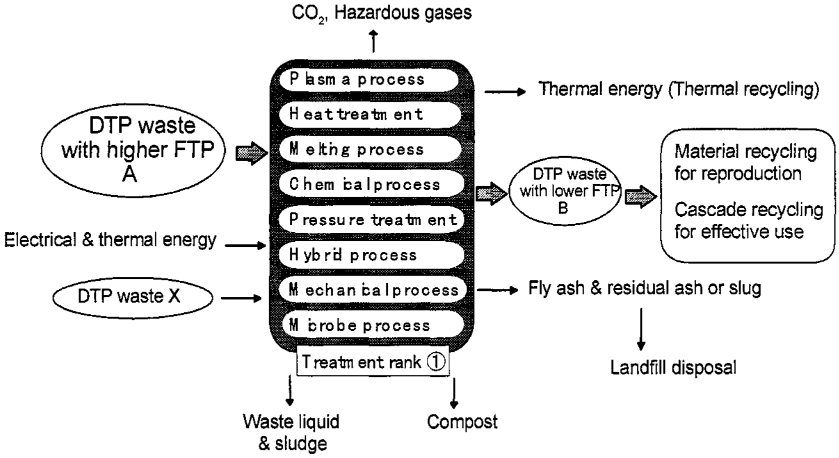

Figure 1: Material flow and energy flow in waste treatment process.

energy accompanied by the waste treatment of the rank ①, in which a DTP waste A with higher FTP is treated together with another DTP waste X. As a result of one of the treatments (plasma process, heat treatment, melting process, chemical process, pressure treatment, hybrid process, mechanical process, microbe process, etc.), the product B with lower FTP is supposed to be prepared with a consumption of electrical or thermal energy. Probably the secondary wastes such as CO_2 or hazardous gases, hazardous liquid or sludge may be discharged, and hopefully the wastes such as fly ash, bottom ash or slug are used for material recycling, cascade recycling or compost production. Heat energy by the combustion of municipal refuse should be thermally recycled effectively. Landfill disposal is the last option for DTP waste in the final treatment rank.

4 Assessment system of waste management by Rescue Number

4.1 Definition and formulation of Rescue Number

Development of the total assessment system for waste management is essential to establish the so-called "recycle based society". A new concept of "Rescue Number", which is abbreviated as RN hereafter, is recently introduced in a collaboration research project of ResCWE in Nagoya University, Japan, in order to develop the assessment and search system for the optimum waste management. RN is generally defined as a function of FTP and FUW by the following equation:

$$(RN) = f[(FTP), (FUW)]. \quad (3)$$

RN is an assessment index for searching the waste material, which needs an urgent treatment with the first priority, and for searching the best treatment

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technology with low energy, low cost and low environmental burden. In this sense, the higher FTP and FUW are, the higher RN will be with a multiplier effect. Therefore, RN can be expressed as

$$(RN) = (FTP) \times (FUW). \tag{4}$$

Moreover, if we define the rescue index as

$$(RI) = (FTP)/(FUW), \tag{5}$$

this shows an index which indicates the best treatment technique for DTP waste, because much decrement in FTP value can be attained with small decrement of FUW value.

4.2 Multistage process and goal of waste treatment

Treatment of DTP waste can not be accomplished by only one rank, but several treatment ranks are required to reduce the hazard below the environmental standard. Figure 2 shows the cases of multistage process for DTP waste treatment on the (FTP) – (FUW) diagram. The treatment of the rank ① from the plot A to B corresponds to that of ① in Figure 1, where the decrement of FTP is $(FTP)_A - (FTP)_B$, and that of FUW is $(FUW)_A - (FUW)_B = (\Delta FUW)_1$.

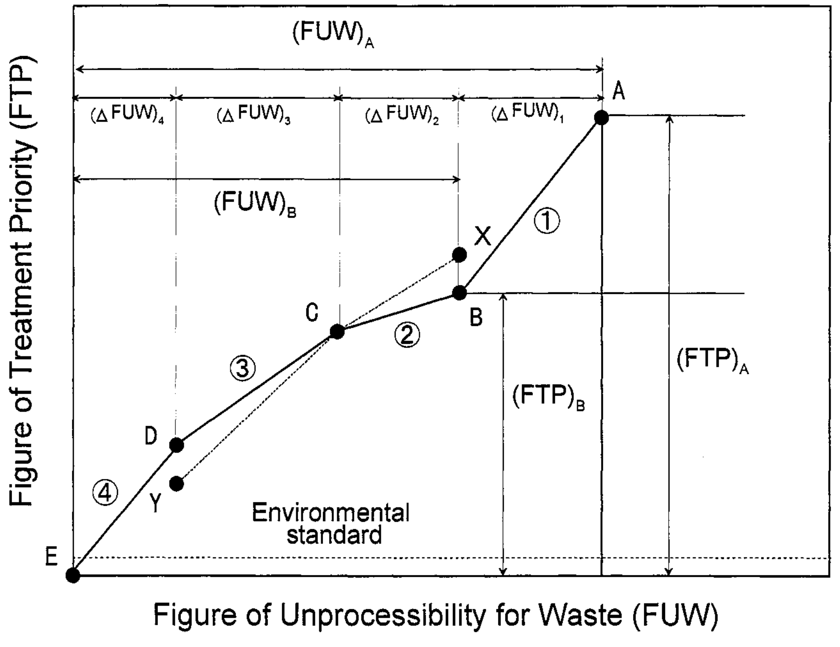

Figure 2: Multistage process for DTP waste treatment.

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The total decrement of FUW is evaluated by

$$(\Delta FUW) = \sum_i (\Delta FUW)_i. \qquad (6)$$

It is noted that RI is expressed by the slope of the line ①. Through the multistage process as shown A→B→C→D in Figure 2, DTP waste is disposed finally as harmless material. The total assessment for the treatment of DTP wastes is carried out by decrement value of ΔFUW. In other case of waste treatment, two kinds of wastes (B and X in Figure 2) with different FTP values are treated simultaneously to produce a new material C with lower FTP value. Furthermore, we can suppose another case when two kinds of products (D and Y in Figure 2) with different FTP values are obtained by the treatment of DTP waste (C) with higher FTP value. Thus, various kinds of waste treatment cases can be plotted on the (FTP) – (FUW) diagram, which makes it easy to make a visual assessment of the waste management proposals. Therefore, our goal for waste management is to reduce the RN.

4.3 Development scheme for the quantitative assessment system

A quantitative assessment system of RN is required for optimization of waste management. Figure 3 shows the development scheme to establish the RN assessment system of DTP waste. The definition and formulation of RN, FTP and FUW have been done already in the previous sections as well as the determination of sub-items of FTP and FUW (as shown in the hatched part in Figure 3). Some modifica- tions of the above sub-items would be possible through the case studies on many kinds of DTP waste treatments. Now the normalizing procedure and determination of the units for FTP and FUW are necessary to compare the numerical values between the different items. Moreover, we should determine the weighting parameters for each item of FTP or FUW. This task is considerably difficult to be accomplished, because the weighting factors include too ambiguous criteria and too subjective judgments to perform a strict numerical analysis. Commercially avail- able risk database on chemical substances are helpful to complete the FTP database. Other database such as LCA

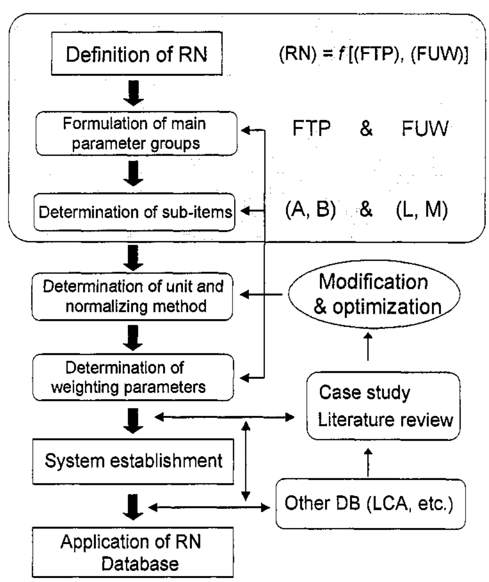

Figure 3: Development scheme for RN assessment system of DTP waste.

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will be referred for refinement of the FUW data. In order to establish a reliable RN database, the modification and optimization will be carried out by the literature survey and case studies on waste treatment technologies.

5 Qualitative assessment of various ceramic waste treatments

5.1 FTP of ceramic wastes

The industrial wastes discharged from the ceramic companies or public facilities are classified as: (1) conventional ceramic wastes such as cement, glass, asbestos or porcelains, (2) new structural ceramics such as SiC, Si_3N_4, ZrO_2, WC-Co or these composite materials and (3) new functional ceramics for electronic, magnetic or optical uses such as $YBa_2Cu_3O_x$, $BaTiO_3$, $Pb_{1-x}La_x(Zr_y,Ti_{3-y})_{1-x/4}O_3$, $BaFe_{12}O_{19}$, Li(or Ta)NbO_3 or rare earth metal oxides.

Conventional ceramic wastes have a depletion problem of landfill site, as the amount of demolition wastes is considerably large and hazardous chemical components are occasionally included in these ceramic wastes. New structural ceramics, which require much energy and precious resource for ceramic production, are expected to recover as the powdery state for re-sintering after the usage of sintered body. From a viewpoint of toxicity of ceramic waste, the new functional ceramic wastes have high value of FTP, because they contain higher concentration of heavy transition metals (Zr, Nb, Ta, Pt, etc) and hazardous metals (Cd, Pb, As, Bi, etc) easy to dissolve in acid or alkaline solutions.

5.2 FUW of ceramic wastes

The value of FUW for ceramic wastes is rather high because of their high chemical and mechanical stability, and kinetic difficulty to decompose the solid wastes. For conventional or traditional ceramic wastes, the closed material recycling of used or broken ceramic wastes is so difficult from the economical and energetic standpoints to guarantee the quality of the recycled products, that a cascade recycling for low level use of ceramics is common, for example, for the roadbed materials. New structural ceramics have higher mechanical, thermal or chemical stability, which results in the difficulty in decomposition without much consumption of heat energy and CO_2 generation. Furthermore, recently advanced structural materials have typical composite structures that contain many kinds of ceramic, metallic or polymer components with different morphologies and microstructures. Such materials have higher FUW on account of the difficulty in separation and extraction of recyclable resources. On the other hand, new functional ceramics for electronic, ionic, magnetic or optical uses contain different kinds of elements, some of which are toxic, rare and precious. The extraction of these elements is also difficult because they are assembled in complex devices.

The above consideration leads to a conclusion that new structural and functional ceramic wastes possess high value of FUW. Appropriate treatment to decrease the FTP is required to establish the material recyclable society. WC-Co

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cemented carbide is one of the representative example of advanced ceramic material which needs an appropriate recycling.

6 Assessment of recycling of WC-Co cemented carbide scraps

6.1 Recycling necessity of cemented carbide scraps

Cemented carbide tools of WC-Co cermet are industrial materials used widely as cutting tools or dies. About 3,000-4,000 tons of WC-Co tools are fabricated annually in Japan and most of the scraps are exported to foreign countries or stocked in the domestic country without recycling. The present recycling rate is at most 20% in Japan and 25% in EU and USA. Though annual world mine production of W and Co is 31,000 tons and 29,900 tons, respectively, most of them are distributed to China and Africa. From the viewpoint of stable supply of these rare and precious metals, recycling of both metals is greatly desired. As far as the risk problem of cemented carbide scrap waste, the toxicity or hazard of solid compact is minor, but the powdery particles or dissolved ions of such heavy metals will be harmful for human life, if they are incorporated via secondary degradation process in a special environment. Controlled-type stockyard is required for long-term preservation of the scraps. Therefore, the FTP value of cemented carbide scraps would be higher than the other ceramic wastes described in 5.1.

6.2 Assessment of waste treatment of WC-Co cemented carbide scraps

Figure 4 shows the diagram of production and recycling processes of WC-Co cemented carbide. Normally WC powder is prepared by carburization of W powder that is prepared by reduction of WO_3 obtained from tungsten containing ore. On the other hand, Co powder is prepared by reduction of cobalt oxide refined from Co containing ore. The mixed powder of WC and Co at an appropriate composition is then pressed to form a green compact. After the calcination process, the molded compact is sintered at higher temperatures of 1,350-1,400°C.

Conventional recycling processes of WC-Co cemented carbide scraps are classified as follows.

1) High temperature fracture method: Cemented carbide scraps are heat-treated in an inert atmosphere at 1800-2300°C, then quenched, when cobalt binder form a sponge-like solid which facilitates the pulverization of the scrap. This process needs high energy for heating and results in the formation of undesirable phase of W_2C, W_3Co_3C and free carbons.
2) Cold stream spraying method: High pressure air is sprayed on coarse target of carbide chips (chip size < 3 mm in diameter) in a chamber held below 0°C. Pulverization occurs by the collision of chips under the adiabatic conditions. This process needs a high cost pretreatment for coarse grinding and has a disadvantage of impurity contamination in the recovered powder.
3) Mechanical breakdown method: The carbide scraps are break down directly

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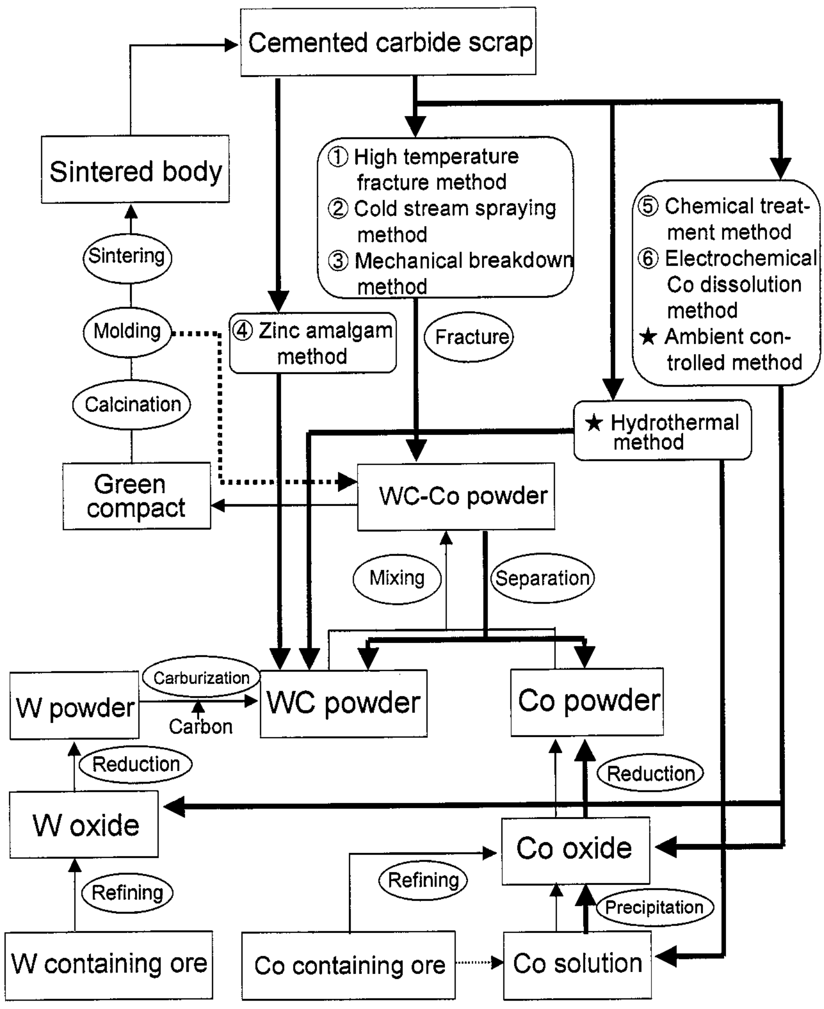

Figure 4: Production and recycling processes of WC-Co cemented carbide.

by high-energy attriter or ball milling. This process needs much energy with low efficiency.

4) Zinc amalgam process: Molten zinc or its vapor has a contact with cemented carbide scrap at about 950°C in an inert atmosphere to promote the diffusion of zinc into cobalt phase and form zinc-cobalt alloy. Then the swelled scrap is treated at higher temperature at 1000-1050°C under a reduced pressure to vaporize zinc vapor. Resulted porous sponge of the scrap is easily pulverized. This process has a problem of the contamination by zinc into the recovered powder.
5) Chemical treatment methods: Oxidation treatment of cemented carbide scrap

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is performed to form WO_3 and $CoWO_4$ in air at 750-900°C and then to prepare Na_2WO_4 and Co at 200°C in an autoclave. Another method is to treat cemented carbide scrap with the mixture of $NaNO_3$/$NaNO_2$ and $NaCO_3$ at 600°C in a rotary autoclave to form Na_2WO_4 and Co. These processes need to return the scraps to the refining stage of both metals.

6) Electrochemical Co dissolution method: Co phase is electrochemically dissolved in a $FeCl_2$ aqueous solution.

Considering the advantage and disadvantage of the above treatment methods, we developed new recycling systems of WC-Co scraps by a dry process (ambient controlled method) and a wet process (hydrothermal method) in order to reduce FUW. Detailed information can be obtained by the reference in this volume [3].

7 Conclusions

Environmental risk and treatment technology for waste management of are assessed by a new concept of RN, which is a function of FTP and FUW. FTP is a linear combination of risks for direct humane life and global environment, which are multiplied by weighting factors conspicuous for waste management. FUW is also a linear combination of difficulties in waste treatment, which are multiplied by analogous weighting factors. Assessment of the present state and future planning of DTP waste management will be performed by using numerical database of RN

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