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# The simulation of the liberation and size distribution of shredder products under the material characteristic coding method

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This paper establishes a coding method system including the liberation and size distribution of recycling materials in the shredder operation. Every particle in the shredded product becomes a code number using the liberation model and size distribution equation transforming of weight percentage into particles number percentage. One set of database can be obtained after all particles have been coded. This database is suitable for the size reduction operation in the process simulation of waste recycling. Coupling with the developed air classification, sizing and separating operations, the whole process simulation will be completely established for diversified application.

A typical simulation for the rolling cutting shredder product of waste TV had been demonstrated under this coding system. The breakage size distribution of Gaudin and Schumann equation were selected for the shredding operation simulation. The Gaudin's liberation model was suitable for the liberation simulation. Both of these equations were transformed weight percentage into particles distribution for the necessary of particle coding method. A better recycling operation for this shredded solid waste can be concluded from the comparison of simulation results with their sorted grade, recovery or economic of materials in different processes.

Keywords: computer simulation, shredding, liberation, recycling.

## Introduction

The policy for disposal the solid waste in Taiwan has been specified adopting recycling method for different imperfection in diverse disposal methods. After the installation of the recycling plants for all kinds of solid waste such as discarded electric appliance, used car and tire, etc., the capacity of processing these recycling waste will be up to near 100% of their production. In the operation of these plants, it can be the sorting of metal and other materials is not in well conditions. Even more than 40% of recovery materials is the mixture of more than two kinds of material. Of course, some of them are inherit locked condition such as the electric power wire, it still can be found many shredded particles didn't liberate completely. If there has a detail analysis of shredding and sorting unit operation and the whole process simulation, an obvious improvement will be obtained easily. That will be derived not only the recycling of these materials perfectly but also earn some economic benefit from the modification of these recycling process.

Up to date, the process for treatment of the recycling solid waste has no any obvious changes. The same equipment and process using in Japan or other country had been introduced into Taiwan market in their originally operating conditions. However, the characteristics of local recycling solid waste are more or less different from that of other countries. Developing a useful process simulation model for local usage is the duty and the privilege of recycling academic organization [1]

For experiment of recycling solid waste, the large size of every particle and the rare content of diverse combination causes samples for testing are in large scale. There is even no difference between experimental and demonstrating equipment. This difficulty offers an idea for simulation of the recycling of recycling solid waste process by computer coding method.

The scope of this paper is focused on the code transformation of comminution operation. A large, locked particle of solid waste must be crushed or ground to small particles for the purpose of liberation and separation. This size reduction operation will disappear a particle and will generate a lot of fine particles. What is the code of these generated fine particles and how to get the database of these particles code are two important objectives of this research study.

## Experiment/Modeling

### Coding theory for a recycling particle

The first step for recycling process simulation is survey the composition and characteristics of each recycling particle. Before this work, we have to identify inherit physical characteristics to be used in the separation and sorting process. According to the unit operation mode for sorting, it is reasonable to take advantage of the necessary characteristics such as kinds of solid waste, distribution of individual particles diameter, distribution of bulk density for all of the categories in recycling solid. The experimental survey based on this idea is designed in the progress section. The sampling data of component is close to the data that had published by government yearly book.

Table 1 and 2 express the characteristic items and reference items of recycling particle. The characteristic items are waste kind, particle shape, particle size and weight. The reference items are quantity, moisture, liberated condition and compression ratio of individual particle.

Table 1. Characteristic items for coding a recycling solid particle.

| Item | Coding purpose and descriptions |
|---|---|
| Waste kind | Including 12 kind of different materials |
| Particle shape | Drag coefficient selection, volume calculation |
| Particle size | Volume calculation, 3 or 4 dimension |
| Particle weight | Bulk density, capacity and recovery percentage calculation |

Table 2. Reference items for coding a recycling solid particle.

| Item | Coding purpose and descriptions |
|---|---|
| ID number | Specific number for programming |
| Quantity | Give similar particles the same ID number to simplify the survey process and reduce database |
| Moisture | Weight or percent moisture contain in particle |
| Liberated or locked condition | To record particles ID number interlocked, packaged or liberated condition. |
| Compressing ratio | A parameter to forecast particle compressing ratio in dimension when sorting |

Items of sampling items such as date for sampling, location and weather are also identified for statistics or further application.

### Simulation process

When simulating process takes place, the computer reads the physical characteristic data of recycling solid particle from the coded data. After statistic operation, the characteristic such kind and ratio of each composition, particle size distribution, bulk density distribution etc., can be obtained. This statistic data can offer the idea to choose appropriate unit operation for this recycling solid waste. The simulation program can divide the raw material into two different files from the calculation and judgment of an operation. Every step in a recycling processing can be simulated in the same operation and results for this processing were obtained.

The simulation program includes four parts, which are statistic part, unit operation part, file management part and interface part. Statistic part shows the component of waste and their particle size distribution, bulk density, interlocked condition, etc. Unit operation part includes the model of shredding, bag rapping, air classification, screening, magnetic separation and dewatering operations. File management part offers append, copy some survey data for further applications. And the last of interface part is a window environment issuing the command or result expression between man and machine interface. All these parts are the assembly of the main program which written by open structure and can be add more other simulation units to enhance their function.

### Unit operation simulation

Each kind of recycling waste has a special particle size distribution, so it can be sorted by screening operation. Gaudin's equation offered a probability of the passage of a spherical particle falling down to a square aperture screen[3]. This is easy to transfer into computer program. However, the recycling waste particles are usually packaged, these interlocked waste probably lose the characteristics of individual size distribution and particle weight. Shredding and ripping operation can make sure these particles liberated.

Air classifier is very common equipment for separating light particles in recycling solid waste. A waste particle in the chamber is supposed to sort out when its falling terminal velocity is less than the up blowing velocity of air stream.

## Results and Discussion

### Particle size distribution function

The shredding product of a discarded solid waste was adopted as example. The width of the cutting tool in rolling cutter is 15 mm. The particle size distribution of this shredded product is analyzed as a straight line in the double log scale as figure 1[2]. The cumulative weight percent is the function of particle size which is so called Gaudin Schumann equation[4], and the from can be expressed as the following equations:

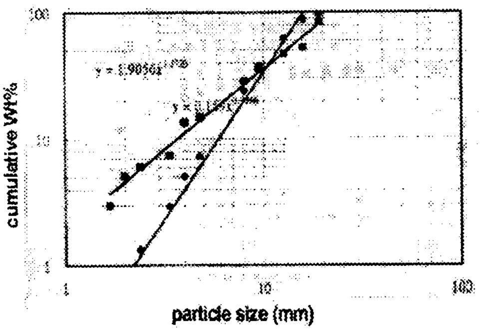


Fig. 1. The particle size distribution curve of a shredded product.

$$Y(x) = 1.9\,x^{1.27} \quad (1)$$

The distribution of another shredded particle is:

$$Y(x) = 0.16\,x^{2.33} \quad (2)$$

Y(x) is the cumulative passed weight % of screen size x (unit in mm).

Eq. (1) was a complex of woody, metallic and plastic part of TV, and Eq. (2) was a plastic-metallic part of TV. These two equations were obeyed the form of Gaudin-Schumann equation in comminution theory.

## Weight fraction in definite size interval

It is quite easy to apply these equations into simulation process. If the size interval for simulated process had been decided, such as the screen aperture $x_1$, $x_2$, $x_3$, .... Etc.(In which $x_1>x_2>x_3>\ldots$). The weight distribution of complex part in discarded TV between these intervals can be calculated directly as:

$$\text{Wt\% of } x_1<x<x_2 = Y(x_1) - Y(x_2) = 1.9\,x_1^{1.27} - 1.9\,x_2^{1.27}$$

$$\text{Wt\% of } x_2<x<x_3 = Y(x_2) - Y(x_3) = 1.9\,x_2^{1.27} - 1.9\,x_3^{1.27}$$

All of the weight distribution of for computation can be obtained from this size distribution function. Of course, the plastic part of discarded TV must be obeyed the function in equation 2.

## Weight in definite size interval

For the coding system of recycling process simulation, the real weight of every particle to be shredded has to measure for the computation of the derived comminuted particle's number and weight. The bulk density($\rho_b$) of the shredded particle has to obtain too. Then, the number of a size interval of size distribution is calculated as:

$$\text{Wt. in size interval } x_1<x<x_2 = (\text{Wt\% of } x_1<x<x_2) \times \text{Wt. of feed} \quad (3)$$
$$= (Y(x_1) - Y(x_2)) \times \text{Wt. of feed}$$
$$= (1.9\,x_1^{1.27} - 1.9\,x_2^{1.27}) \times \text{Wt. of feed}$$

## Component weight in definite size interval

This weight is combined wood, plastic and metal together. The individual component weight can be derived from the component distribution result as Table 3. For example, the wt. of metal in this size interval is:

$$\text{Metal wt. in size interval } x_1<x<x_2 = \text{Wt. in } x_1<x<x_2 \times \text{metal content} \quad (4)$$
$$= \text{Wt. in } x_1<x<x_2 \times 1.9\%$$

Table 3 The component distribution in shredded discard TV

| Component | Wood | plastic | Metal |
|---|---|---|---|
| Complex part | 69.5% | 28.7% | 1.9% |

## Component particle number in definite size interval

The particle number of metal or other component can be calculated from the weight of this component divided by it's bulk density. The general formula is as following:

$$\text{Number in size interval of } x_1<x<x_2 = \text{Wt.}(x_1<x<x_2)/\rho_b \quad (5)$$

In which, $\rho_b$ is the bulk density of metallic grain. The number of metallic particle is

$$\text{Number of metal in } x_1<x<x_2 = \text{Wt.}(x_1<x<x_2)/\rho_{bm} \quad (5a)$$

In which, $\rho_{bm}$ is the bulk density of metallic grain.

## The liberated number in definite size interval

The particles in definite size interval include liberated particles and locked particles. How many particles are free particles and how many particles are locked particles can be computed from the liberation function which was simulated in the liberation test of shredded product. Equation (6) is the liberation equation of Gaudin [4]. This original liberation formula had tested suitable for the liberation of wood, plastic and metal in shredded TV part [2]. The size modulus k for representing the relative particle size is the ration of real particle size x and grain's size g. In artificial product, the grain's size of component such as plastic and metal is very difficult to decide. The g value in equation (6a) to (6c) is the optimum g simulated by Gaudin's equation.

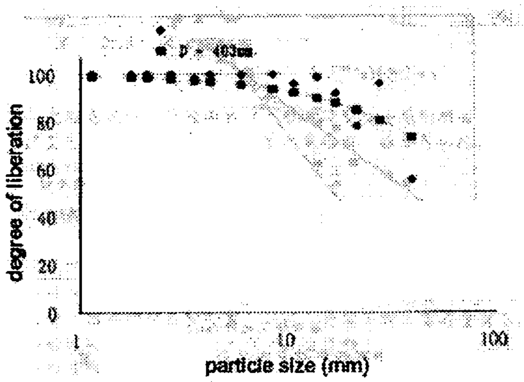


Fig. 2. The liberation curve of woody shredded product.

Wood parts: $Lm(k)= (k-1)^3/k^3$ , in which $k= (403mm/x, mm)$ (6a)

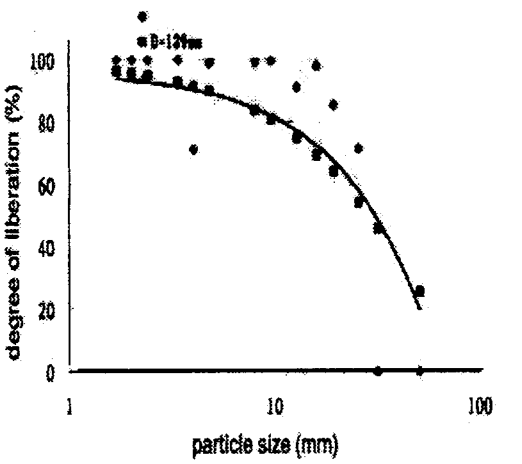


Fig. 3. The liberation curve of plastic shredded product.

Plastic material: $Lm(k) = (k-1)^3/ k^3$ , in which $k= (140\ mm/ x, mm)$ (6b)

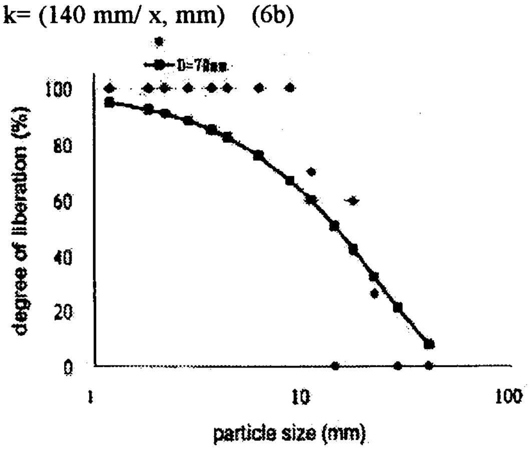


Fig. 4. The liberation curve of metallic shredded product.

Metallic material: $Lm(k) = (k-1)^3/ k^3$ in which $k= (70\ mm/ x, mm)$ (6c)

From these equations, the number of liberated grains can be obtained by getting particle size x in to equation (6) and (6a). For example, particle size of 5 mm grains, the degree of liberation is calculated as following.

For wood material, there is

$k= (403mm/5\ mm)= 81$ (6a)

$Lm(k)= (k-1)^3/k^3 = (81-1)^3/81^3 = 96\%$ (6)

The 96% of this number of particles are free, and 4 % is locked particle.

For plastic material, there is

$k= (140mm/5\ mm)= 28$ (6b)

$Lm(k)= (k-1)^3/k^3 = (28-1)^3/28^3 = 90\%$ (6)

The 90% of this number of particles are free, and 10 % is locked particle.

For metal material, there is

$k= (70mm/5\ mm)= 14$ (6c)

$Lm(k)= (k-1)^3/k^3 = (14-1)^3/14^3 = 80$ (6)

The 80% of this number of particles are free, and 20 % is locked particle.

There is more or less difficulty for distributing the residue locked particles. The idea of "locked factor" in Gaudin's textbook can be solved this problem[4]. This is the most complex in all simulation process though the locked particles is just a little portion of all shredded product.

## The coding for these particles

The coding system as the database of computer simulation was adopted for these liberated and locked particles. A 50 bytes coding number cited for a particle has included the material characteristics, interlocked condition and other properties. All the code of shredded TV particles in this process is the same as sampling particle but in the simple form, which many items are similar. Such as the particles calculating from equation (6a), 96% of 5 mm wood particles are all in the same code. However, a small portion of metallic particles may be content of iron, cupper, aluminum, or combination of two, even three. It has to do more detail analysis to describe these free or locked particles.

## The coding database

After this tenuous calculation process, a piece of discarded TV can be converted into a database under this coding system. This database is useful in the computer simulation of the progress recycling operation for this shredded TV. A segment example of this data code is shown in Table 4.

Table 4. A segment of data code of a shredder product.

| id | kind | shape | length | broad | high | thick | weight | number | psl | 投影面積 | lockid | lockdevel | 篩級 | ps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | F | 1 | 5.63 | 3.85 | 1.18 | 0.00 | 30.20 | 9.0979 | 1 | 1500 | 1 | 0 | 19.1 | Fe |
| 2 | F | 1 | 4.80 | 3.00 | 1.40 | 0.00 | 50.85 | 9.0979 | 1 | 900 | 2 | 0 | 19.1 | Fe |
| 3 | F | 1 | 3.00 | 3.18 | 0.83 | 0.00 | 4.09 | 9.0979 | 1 | 750 | 3 | 0 | 19.1 | Fe |
| 4 | F | 1 | 2.10 | 2.54 | 1.10 | 0.00 | 9.57 | 9.0979 | 1 | 500 | 4 | 0 | 19.1 | Fe |
| 5 | F | 1 | 4.92 | 2.90 | 0.91 | 0.00 | 8.00 | 9.0979 | 1 | 800 | 5 | 0 | 19.1 | Fe |
| 6 | F | 1 | 4.70 | 2.59 | 1.58 | 0.00 | 28.28 | 9.0979 | 1 | 1000 | 6 | 0 | 19.1 | Fe |
| 7 | F | 1 | 4.21 | 3.50 | 1.21 | 0.00 | 15.76 | 9.0979 | 1 | 750 | 7 | 0 | 19.1 | Fe |
| 8 | F | 1 | 4.35 | 2.56 | 1.83 | 0.00 | 11.73 | 9.0979 | 1 | 700 | 8 | 0 | 19.1 | Fe |
| 9 | F | 1 | 4.50 | 3.14 | 0.50 | 0.00 | 10.58 | 9.0979 | 1 | 1125 | 9 | 0 | 19.1 | Fe |
| 10 | F | 1 | 3.10 | 3.05 | 0.70 | 0.00 | 13.71 | 9.0979 | 1 | 1000 | 10 | 0 | 19.1 | Fe |
| 11 | F | 1 | 4.20 | 2.40 | 1.26 | 0.00 | 15.10 | 9.0979 | 1 | 875 | 11 | 0 | 19.1 | Fe |
| 12 | F | 1 | 3.23 | 2.70 | 0.50 | 0.00 | 13.71 | 9.0979 | 1 | 625 | 12 | 0 | 19.1 | Fe |
| 13 | F | 1 | 3.85 | 2.11 | 1.02 | 0.00 | 24.92 | 9.0979 | 1 | 250 | 13 | 0 | 12.7 | Fe |
| 14 | F | 9 | 2.52 | 1.72 | 1.34 | 1.12 | 8.78 | 9.0979 | 1 | 350 | 14 | 0 | 12.7 | Fe |
| 15 | F | 1 | 2.52 | 2.02 | 0.54 | 0.00 | 5.72 | 27.2937 | 1 | 437.5 | 15 | 0 | 12.7 | Fe |
| 16 | F | 1 | 3.72 | 1.42 | 0.82 | 0.00 | 9.70 | 27.2937 | 1 | 350 | 16 | 0 | 12.7 | Fe |
| 17 | F | 1 | 5.02 | 1.74 | 0.84 | 0.00 | 6.93 | 9.0979 | 1 | 675 | 17 | 0 | 12.7 | Fe |
| 18 | F | 1 | 2.54 | 2.04 | 1.02 | 0.00 | 5.39 | 18.1958 | 1 | 425 | 18 | 0 | 12.7 | Fe |
| 19 | F | 1 | 4.76 | 2.26 | 0.53 | 0.00 | 9.73 | 9.0979 | 1 | 750 | 19 | 0 | 12.7 | Fe |
| 20 | F | 1 | 3.51 | 2.11 | 1.32 | 0.00 | 10.11 | 9.0979 | 1 | 500 | 20 | 0 | 12.7 | Fe |
| 21 | F | 1 | 3.11 | 2.40 | 0.43 | 0.00 | 9.27 | 18.1958 | 1 | 600 | 21 | 0 | 12.7 | Fe |

## Process simulation program

The simulation program is written by in QUICK BASIC language[1]. It is easy to obtain a simulated sorting product for a recycling process. From these results, we can modify and setup another simulation again to optimize the process.

## Example of simulation

An example of air stream sorting process had simulated and the result was shown in Fig.5. In this simulation process, we specify all the shredded particles data as the feeding of this unit operation[5,6]. Metallic grains can be concentrated in the sink product. The grade of concentration and the recovery of metal are two controversial curves under different ventilation velocity. The optimum of this sorting operation may be chosen the cross point of these two curves, which air stream velocity is 25 m/s, ant the recovery of metallic grains is near 80%.

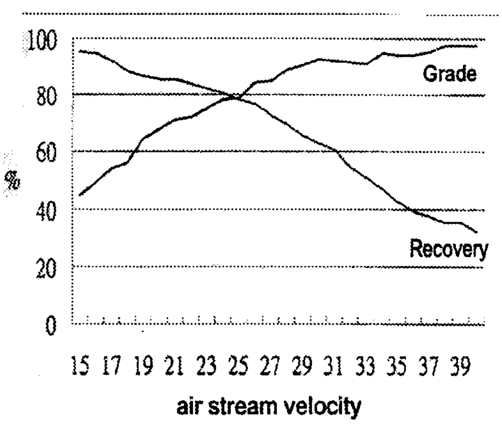


Fig. 5. The relationship between the air stream velocity of classifier and the grade, recovery of sorted shredded product.

Another optimum condition can be decided on the value of sorted materials. The economic value of concentrated metal and floated light material will change depending on the sorting velocity. Fig. 6 showed the relation between market value of sorted materials and sorting velocity. The optimum condition is the top of that curve, in which the sorting velocity is 26 m/s and the value is near 11 NT$/kg.

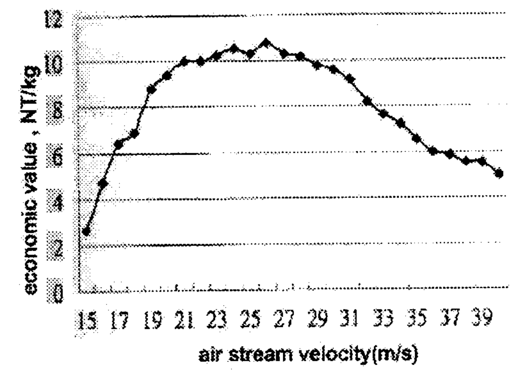


Fig. 6. The relationship between the air stream velocity of classifier and the economic value of sorted shredded product.

## Conclusions

A coding method including the liberation and size distribution of recycling materials in the shredder operation was described. Every particle in the shredder product becomes a code number using the liberation model and size distribution equation transforming of weight percentage into particles number percentage. One set of database can be obtained after all particles have been coded. The transformation steps with an example were explained detail. This database is suitable for the size reduction operation in the process simulation. Coupling with the developed air classification, sizing and separating operations, the whole process simulation will be completely established for diversified application.

A typical simulation for the rolling cutting shredded product of waste TV had been demonstrated under this coding system. The breakage size distribution of Gaudin and Schumann equation were selected for the comminution operation simulation. The Gaudin's liberation model was adopted for the liberation simulation. A better recycling operation for this shredded waste can be concluded from the comparison of simulation results and the economic value of sorted products in different processes.

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