Recycling of WEEE by Magnetic Density Separation

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Abstract: The paper introduces a new recycling method of WEEE: Magnetic Density Separation. By using this technology, both grade and recovery rate of recycled products are over 90%. Good separations are not only observed in relatively big WEEE samples, but also in samples with smaller sizes or electrical wires.

Keywords: recycling; WEEE; density separation; magnetic density separation; solid waste

1 Introduction

In the last decade, high growth rates in electronic industries have led to huge amounts of waste of electrical and electronic equipment (WEEE). The disposal rate of WEEE is accelerating because the global market for electronics is far from being saturated and on the ground that the lifespan of electronic goods is becoming shorter. WEEE accounts for 4% of all municipal waste in European Union (EU) [1]. In 2005, EU produced 8.3-9.1 million tones [2] and yet about 90% of WEEE is landfilled, incinerated or recovered without any pre-treatment [2]. The European commission estimated that WEEE would grow annually 2.5% and would reach about 12.3 million tons in 2020 [3].

WEEE is one of the most complex waste streams in terms of materials and components. With a number of hazardous chemicals and components, as lead in printed circuit boards (PCB) and cadmium in semiconductor chips, WEEE may cause serious environmental problems if not properly recycled or disposed of. However, WEEE contains significant quantities of valuable materials such as metals (66%), precious metals, high quality plastic (19%) and other components which can be profitably be recovered. The main valuable metals contained in WEEE are copper, lead, iron, aluminum and zinc. In addition, WEEE involves precious metals, like gold, platinum, palladium and silver, which are used in the manufacturing of electronic components [4]. Because of the potential risks of WEEE and the considerable resources and energy contained, improving of WEEE recycling is crucial for both economy and environment.

Zhang et al discovered that the metal distribution, in personal computers (PC), for instance, is a function of size range (Figure 1) [4]. It is easy to be observed that aluminum is mainly distributed in the coarse fractions (> 6.7mm), and about 50% exists in the > 9.5mm fractions. However, other metals are primarily in the fine fractions (< 5mm). Therefore, it is essential to upgrade the metal content by screening and furthermore, by chosen an optimal separation technique for the different sizes.

![Figure 1. Metal distribution in size range](image-url)
based on the interaction of gravity, buoyancy, drag and acceleration. In a wet jig, a bed of particles is periodically lifted by a water column. As the mass of particles settles down onto the screen, a segregation develops according to density. In the jigging treatment, important operational parameters of the jig, as stroke length, jiggling speed and initial bed height, play key roles in the process. It has a rather wide range of treatment: 1-150 mm [6].

2.3 Eddy Current Separation

The operability of eddy current separation (ECS) is based on the use of rare earth permanent magnets. It was initially developed to recover non-ferrous metals from shredded car scarp and municipal solid waste. The technology separates materials on the basis of the particles’ ability to conduct electricity. Particles that conduct electricity are charged by electrostatic induction and attracted to an electrode. It has a workable size range of >5mm [7].

2.4 Sink-Float by Heavy Medium

Sink-float is a gravity method for separating particles with different densities. By employing a medium with a density about 3000 kg/m³, particles, like Al, which has a density lower than that of the medium float; particles with a higher density, like Cu and Pb, sink. By using sink-float separation, it is possible to obtain products with both high grade and recovery after separation, however, for fine particles, this process may have a low capacity, since it takes long time for fine particles to be settled, especially when the particles have similar density to the medium.

2.5 Kinetic Gravity Separation

The concept of kinetic gravity separation (KGS) is the differences among particles on terminal velocity. Particles are fed at some point in a stream of fluid that is flowing in a horizontal direction. Therefore, particles have a horizontal velocity component that is the same as that of the fluid and a vertical component that depends on their density, size and shape. At some level with respect to the feeding point, the particles are collected in a series of compartments that are aligned in the direction of the flow. Particles with a high vertical speed end up in the compartments close to the feeding point, whereas particles settling at a lower speed are collected further downstream. The KGS is able to process metal-rich materials from WEEE in the size range 0-15 mm with 95% recovery rate [5]. But a pro-process of screening is necessary for input materials, in order to avoid fine particles with high density misplaced in the low density fraction.

As summarized above, most of the mechanical processes are dependent on not only the density of particles but also size and shape of particles influence the segregation.

3 Magnetic Density Separation

Magnetic density separation (MDS) is utilized in recycling and mineral processing industry since 2007. By changing the magnetization of the liquid, the MDS process provides a good solution for minerals and precious metals concentrating and polymers separation [8-10]. Magnetic fluid was used for recycling of WEEE waste in 1999 in Germany [11]. Advantages of MDS are the high capacity per hour, low operating costs, environmental impact and suitability to process large amounts of particles with a wide size range. One of the important applications of the MDS in recycling industry is separation of light and heavy non-ferrous products in bottom ash, which provides a promising application of MDS in recycling of WEEE.

3.1 Principle of MDS

The basic principle of the MDS is to use magnetic liquid as the separation medium. Different from a medium with a single density, the density of the magnetic liquid in a special magnetic field varies with the distance from the magnet. Such liquid contains magnetic iron oxide particles with a size about 10-20 nm, which suspend in water. The apparent density of the liquid in a magnetic field increases because the magnetic nano-particles are attracted by the magnet. The apparent density of the magnetic liquid (ρ_app) in magnetic field is determined by:

$$\rho_{\text{app}} = \rho_{\text{liquid}} + \frac{2\pi MB_0}{g\omega} e^{-2\pi z/w}$$

Where ρ_liquid and M are the density and the magnetization of the magnetic fluid, respectively, B_0 and w are the properties of the magnet: magnetic induction and wavelength of the field. z is the vertical distance from the magnet.

Due to this reason, MDS provides the opportunity to separate different materials in one process. The apparent density is dependent on both the magnetization of the magnetic liquid and the magnetic field. By varying the magnetization, when the magnetic field is certain, the apparent density decreases with z (Figure 2).

3.2 Terminal Velocity

The terminal velocity of a particle (Re=2~500) in magnetic liquid results from the balance of drag, gravity and buoyancy:

$$v = \sqrt{\frac{2(\rho_p - \rho_{\text{app}}) V g}{C_{\text{app}} A}}$$

Where g is the acceleration of gravity, ρ_p is the density of the particle. V and A are the volume and the cross-section area of the particle, and C is the coefficient of drag, which is a function of the shape of the particle.
Figure 3 describes the theoretical trajectories of three aluminum particles with different shapes and sizes in MDS ($M=3000$ A/m): two particles with drag coefficient 0.8 and one particle with $C=2$; two of the particles have a thickness of 0.5mm, and the other one is 1mm thick. As addressed in the figure, within 1.5s, all three aluminum particles settled at a height of 0.06m from the magnet surface. Obviously, for smaller particles, longer time is necessary for separation. Even so, however, compared with other techniques, MDS requires much shorter time. As shown, the cut point of the separation can be placed according to density only. The size and shapes are much less relevant, which is because that particles stops settling when the density of the particle is equal to the apparent density, regardless of the shape or size. Therefore, theoretically, size and shape of particles do not influence the MDS.

4 Experiment

4.1 Materials

Three samples were processed by MDS, in order to understand the influence of particle size and shape on WEEE recycling by MDS. Samples I and II were from a WEEE recycling plant located in Belgium. Although both of them were pre-processed, there were still considerable amount of valuable metals contained in both fractions which can be extracted by MDS. Additionally, special attention was given to electricity wires (sample III) in the wake of their variable densities and shapes. The magnetic particles were removed since the attraction of the magnet on ferrous particles affects the trajectory of non-ferrous particles in MDS.

1) Size distribution: As presented in Figure 5, the particles of Sample I are much coarser than that of Sample II and III. Over 75% of Sample I has a size larger than 8mm, nevertheless, almost all Sample II and III are smaller than 8mm.

2) Compositions: Nearly 50% of Sample I is made up of non-ferrous metals. Compared with I, the non-ferrous contents are much less: about 10% and 20% respectively. Moreover, the 20% of non-ferrous in Sample III is mainly Cu wires. In these all three samples, electricity wires coated with plastics are found. In both Sample I and III, these coated wires occupy approximately 8%, but only less than 1% were discovered in Sample II. In samples II and III, plastics constitute up to 70 wt%.
Shape analysis was only carried out for the metallic particles in Sample I, since the metallic constituent includes more complex shapes than others and Sample II and III were too fine to be handpicked for the analysis. Figure 7 shows that 19% of the metals are folded sheets. Further analysis discovers that the cooper have a shape of either wire or haywire.

Density: It is obvious that the metals have certain densities according to the types of materials. However, others may have varying densities based on the compositions. For instance, the density of the PCB varies between 1600 kg/m³ and 2000 kg/m³ depending on the proportion of the metals contained. The wires coated with plastics have variable density changing from 2000 kg/m³ to 2200 kg/m³.

4.2 Set up

The MDS is basically consisted of a separation channel and a special designed magnet placed underneath. The separation channel is placed on the magnet with an angle about 2.5% in order to create a natural overflow. The MDS produces two products: float and sink. The magnetic fluids (3000 A/m), and the light components flow over the magnet and end up in the sieve (Figure 8). Conversely, the heavies sink on the bottom of the channel.

5 Results

The results of the separations by using of the MDS are presented in Table 1. 90% grades for non-ferrous heavies with high recovery rates in the sink fraction are possible for all three samples. For Sample I and III, the grades of the heavies raised to more than 98% from 50% and 20% respectively. The heavies in Sample II are concentrated to 90% from 10% and with a recovery rate higher than 92%. However, because of the complexity of the shapes especially for the wires, small amount of copper and coated wires were found in the float and sink fractions respectively. This was clearly observed in the sample III. The reason of it is that the particles and wires are easily intertwined with each other, and fine plastics or other lights are trapped by the disordered wires.

The high grade and recovery in both float and sink products illustrate that the MDS is able to concentrate both lights and heavies from WEEE, even if the sample may contain various types of shapes and wide range of sizes.

Acknowledgement

The present work is partly of the work is sponsored by the European Commission under the FP7 Collaborative project “W2Plastic”, Grant Agreement No. 212782.

References


