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Journal of Hazardous Materials 159 (2008) 230–234
Journal of Hazardous Materials
www.elsevier.com/locate/jhazmat

Electrostatic separation for multi-size granule of crushed printed circuit board waste using two-roll separator

Jiang Wu, Jia Li, Zhenming Xu *

School of Environmental Science and Engineering, Shanghai Jiao Tong University, 800 Dong chuan Road, Shanghai 200240, People's Republic of China

Received 15 December 2007; received in revised form 21 January 2008; accepted 4 February 2008
Available online 14 February 2008

Abstract

The electrostatic separation is an effective method for recycle of crushed waste electrical and electronic equipment (WEEE). However, the robustness of the classical roll-type separator is vulnerable because of its sensitivity to variation of granule size. A new "two-roll type corona-electrostatic separator" was built to overcome the limitation of the classical one considering the actual situation of the industrial application which always contains granule with different size. Multi-size granule of crushed printed circuit board (PCB) wastes was used for investigation and the results showed that the efficiency of the separation process was improved by using the new separator. Compared with the process (lower voltage) performed on the old separator, the metal products increased 34% while the middling products reduced 73%, respectively. Compared with the process (higher voltage) performed on the old separator, the metal products increased 22% while the middling products reduced 59%, respectively. In addition, the metal component of the middling products using new machine notably decreased, 33% (new machine) compared with 58% (lower voltage) and 66% (higher voltage). The efficiency of the separation process is enhanced compared with the classical one.

Keywords: Waste printed circuit board; Multi-size granule; Two-roll electrostatic separator

1. Introduction

The roll-type corona-electrostatic separator is a classical machine for recycling metals and plastics from waste electrical and electronic equipment (WEEE) [1–5]. In general, the classical separator has several electrodes (Fig. 1): a grounded rotating roll electrode and other active electrodes (corona-electrostatic) connected to a DC high voltage supply. The granular mixture to be separated is fed on the surface of the rotating roll at a certain speed and pass through the electric field that generated between the roll electrode and active electrodes. After an intense "ion bombardment", nonconductive particles are charged and pinned to the surface of the rotating roll electrode by the electric image force while the conductive ones are charged by electrostatic induction and attracted towards the electrostatic electrode [5]. As a classical one, the roll-type corona-electrostatic separator has shown it's validity in laboratory experiments or industrial application. However, it still faces some problems about robustness. It is sensitive to some noise factors, such as the material characteristics, the granule size and the ambient condition and leads to a low efficiency eventually [6–8].

Under the laboratory conditions, the granule mixture can be sorted in several groups according to the size. Nevertheless, this is not true for the actual situation in the industrial application which always contains granule with different size. For the corona-electrostatic separation of such multi-size granule mixture, the low efficiency essentially comes from the variation of forces acting on particles in the corona-electrostatic field. The effects are shown in two aspects, one is the change of the conductive particle's trajectory and the other is change of detachment angle of nonconductive particle [6]. All of these make a big trouble for the classical separator.

The aim of this paper is to build a new separator, "two-roll corona-electrostatic separator", to overcome the weakness of classical one: the low efficiency caused by the variation of granule size. A series of experiments were carried on this new machine to investigate its separation ability of multi-size granule from crushed printed circuit board (PCB) wastes.

* Corresponding author. Tel.: +86 21 54747495; fax: +86 21 54747495.
E-mail address: zmxu@sjtu.edu.cn (Z. Xu).

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doi:10.1016/j.jhazmat.2008.02.013

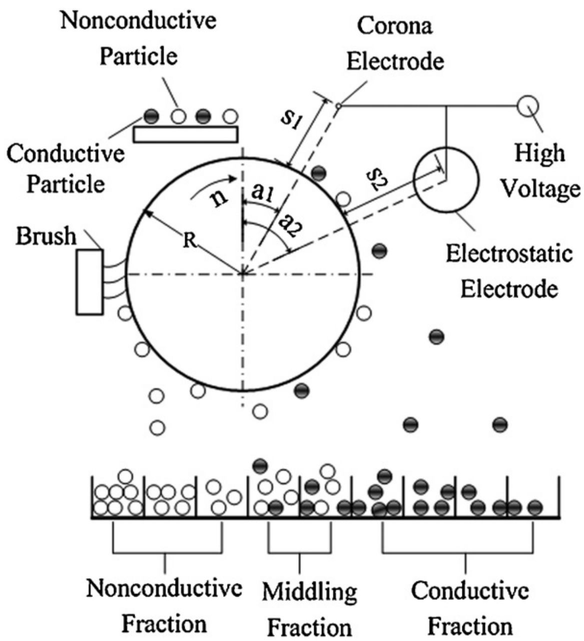

Fig. 1. Schematic representation of roll-type corona-electrostatic separator.

2. Experiment setup

2.1. Two-roll corona-electrostatic separator

A laboratory "two-roll corona-electrostatic separator" (Fig. 2) was employed for the experimental study of granular mixture separation. It consists of two classical roll-type separators (part A and part B) that arrayed in the vertical position. Each one has the same electrode configuration (a grounded roll electrode, a wire-type corona electrode and a cylinder electrostatic electrode). Two chutes were used to collect the middling fraction or the nonconductive fraction of the first separation, and send them to the next step as materials of the second separation. Each part is provided with an electromagnetic vibratory feeder and a monolayer of granular material can be formed on the surface of the rotating roll electrode. The products of the electrostatic separation (process A and B) are recovered in several collecting tanks.

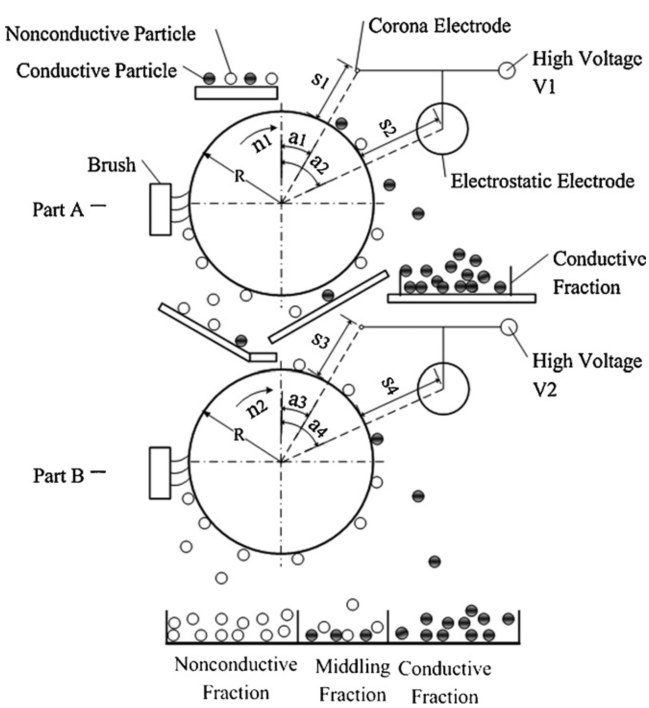

Fig. 2. Schematic representation of the two-roll type corona-electrostatic separator.

Table 1
Parameter setting of separation process

Group	Parameter setting
1	$U = 20\,\text{kV}$ $N = 60\,\text{rev/min}$ $a_1 = 25^\circ$ $a_2 = 75^\circ$ $s_1 = 60\,\text{mm}$ $s_2 = 80\,\text{mm}$
2	$U = 30\,\text{kV}$ $N = 60\,\text{rev/min}$ $a_1 = 25^\circ$ $a_2 = 75^\circ$ $s_1 = 60\,\text{mm}$ $s_2 = 80\,\text{mm}$
3	
Part A	$U = 20\,\text{kV}$ $N = 60\,\text{rev/min}$ $a_1 = 25^\circ$ $a_2 = 75^\circ$ $s_1 = 60\,\text{mm}$ $s_2 = 80\,\text{mm}$
Part B	$U = 30\,\text{kV}$ $N = 60\,\text{rev/min}$ $a_1 = 25^\circ$ $a_2 = 75^\circ$ $s_1 = 60\,\text{mm}$ $s_2 = 80\,\text{mm}$

In order to investigate the ability of new machine for separating multi-size granule mixture, a classical corona-electrostatic separator was used as a comparison.

2.2. Method and material

The experiments consisted of 3 groups. The groups 1 and 2 were performed on the classical separator in different high voltage setting and the group 3 was operated on the two-roll separator. For the corona-electrostatic separation of such crushed PCB wastes, there are many factors that influence the separation efficiency. The preliminary experiments and a comprehensive discussion about these factors have been performed in previous researches [9,10] and the parameter settings that used in the present research are shown in Table 1. The sample (Fig. 3) of multi-size granule mixture was synthetic and prepared by the crushed PCB wastes (got from PCB factory, without electronic elements). It consisted of three different diameter particles, I: 0.091–0.125 mm, II: 0.3–0.45 mm, III: 0.8–1.2 mm (the mass of each kind particle was equal). Each group consisted of 5 tests. Each sample of test was 120 g and contained 25% total conductive particles (copper) and 75% total nonconductive particles (woven glass reinforced resin).

For all above experiments, the product of each test was weighted, respectively, by an electronic balance with resolution 0.1 g. All tests were carried out in ambient air, at a temperature of 20 °C and a relative humidity of 35–45%.

3. Result

The experimental data are given in Table 2. In group 2, the test 2 and test 5 undergone spark discharge, and then, the separation processes were destroyed. Therefore, repeated tests (marked with *) were subsequently performed for them, respectively. The components of middling products are given in Table 3.

Fig. 3. Sample of multi-size granule mixture.

Table 2
Experimental results

	Group	*C* (g)	*M* (g)	*NC* (g)	Mean (g)
	Test 1	21.7	13.4	84.9	
	2	20.8	14.2	85.0	
1	3	22.3	13.0	84.7	$C=21.4$ $M=13.7$ $NC=84.9$
	4	21.0	14.5	84.5	
	5	21.3	13.5	85.2	
	Test 1	23.8	8.6	87.6	
	2*	23.2	9.7	87.1	
2	3	23.0	9.3	87.7	$C=23.5$ $M=9.1$ $NC=87.4$
	4	24.1	8.4	87.5	
	5*	23.5	9.5	87.0	
	Test 1	28.4	3.1	88.5	
	2	29.3	3.7	87.0	
3	3	28.1	3.9	88.0	$C=28.7$ $M=3.7$ $NC=87.6$
	4	29.0	3.5	87.5	
	5	28.6	4.3	87.1	

C, mass of Conductive products; *M*, mass of Middling products and *NC*, mass of Nonconductive products.

4. Discussion

In crushed PCB wastes, there always exist kinds of particles with different size. For the smaller particles (0.091–0.125 mm), even if the voltage is low (for instance, $U=20$ kV), the field intensity is still enough for an efficient separation. However, this field intensity might not high enough for an efficient separation of larger particles (0.8–1.2 mm). The larger nonconductive particles will leave from the rotating roll more easily at a smaller detachment angle and fall into the middling or even the conductor tanks because that the electric image force exerted on a nonconductive particle decreases proportionally with the square of its radius. At the same time, the horizontal motion of larger conductive particle might not enough because of its weight and some of them fall into the middling tanks, too (Fig. 4). This is why the group 1 has the maximum *M* (13.7 g) and the highest component of larger particles in middling products (51%).

Table 3
Components of middling products (mean, mass percent)

Group	Material		Particle size		
	Metal	Nonmetal	0.091–0.125 mm	0.3–0.45 mm	0.8–1.2 mm
1	58%	42%	12%	37%	51%
2	66%	34%	62%	11%	27%
3	33%	67%	28%	31%	41%

Increasing the high voltage is an effective way for improving the separation efficiency [11,12], as well as processing larger particles. The data of group 2 show the effect of this method, the mass of middling products reduces from 13.7 to 9.1 g (mean) and the recovery of metal increases from 21.4 to 23.5 g (mean), respectively. However, the high field intensity leads to other troubles during processing the multi-size granule mixture. Firstly, smaller conductive particles are strongly attracted towards the electrostatic electrode and impact its surface by the electric field force [13]. Then, the trajectories changed and some of them fall along the opposite direction and finally fall into the middling tanks. Secondly, there exist some attractive forces (liquid bridge force, Van der Waals force) between the particles (especially for the fine particles, such as 0.091–0.125 mm) because of their large specific area and intensive surface free energy. This leads to the particles adhere to the roll, motion with it and fall in the middling tanks, especially in the electric high intensity field. These two reasons explain why the component of metal increase with the reduction of *M* (Tables 2 and 3). The middling products can be diminished by increasing the high voltage, however, the

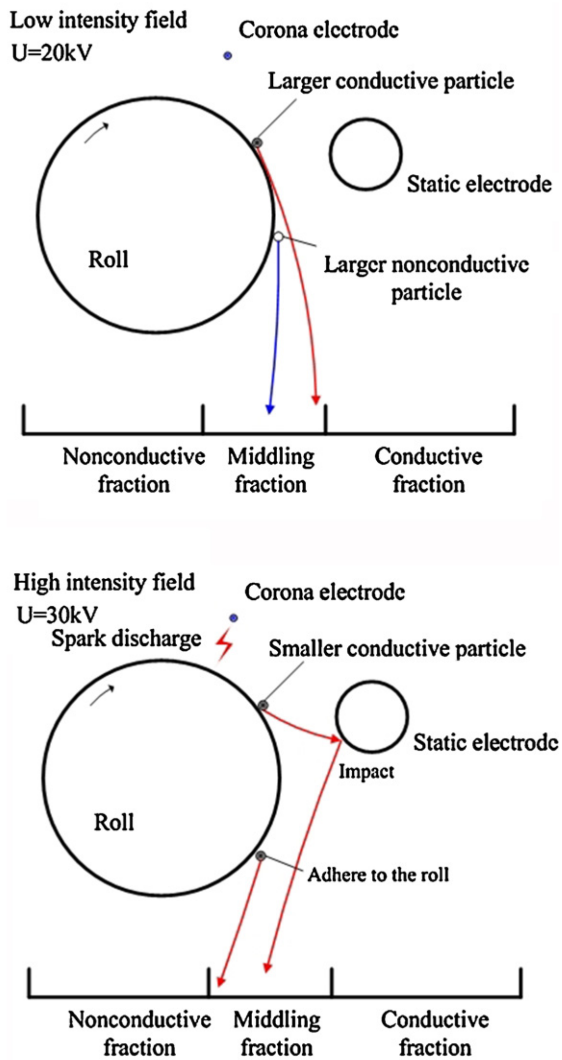

Fig. 4. Bad situations of the separation for multi-size granule mixture using the classical separator.

recovery of metal is still not good because that considerable smaller conductive particles fall into the middling tanks. In addition, in a high field, the smaller particles easily lead to spark discharge between the corona electrode and the roll electrode (Fig. 4). In group 2, two tests (tests 2 and 5) just undergone spark discharge and the separation processes were destroyed (duplicate tests had to be performed for them subsequently). This is very disadvantageous for the industrial applications.

As a result, there is a dilemma for the classical separator to separating multi-size particles: it cannot effectively process the larger and smaller particles in the same electric field. Aiming at this problem, a "twice-step separation" (Fig. 5) was developed for separating such multi-size granule mixture from crushed PCB wastes. A low and a high electric field were generated by the different voltage level in two parts, and then, the smaller particles and larger particles could be processed in these two parts, respectively. Group 3 just shows the effect of this idea and the result is much better than groups 1 and 2. The mass of middling products is only 3.7 g (mean) and decreases 73% and 59% compared with groups 1 and 2, respectively. In general, this is always used as a criterion to estimate the performance of the separation process [8,14]. The recovery of metals is 28.7 g (mean), increases 34% and 22% compared with groups 1 and 2, respectively. Another improvement is the reduction of the metal component in middling products, only 33% compared with 58% for group 1 and 66% for group 2, respectively. This performance depends on not only the second separation, but also the fall between two electric fields. The lower field in part A removes most of smaller particles. It diminishes the chance of impact of smaller particles on the electrostatic electrode and avoids smaller particles falling into the middling tanks. The higher filed, in addition, ensures the lager particles can be processed more effectively in part B.

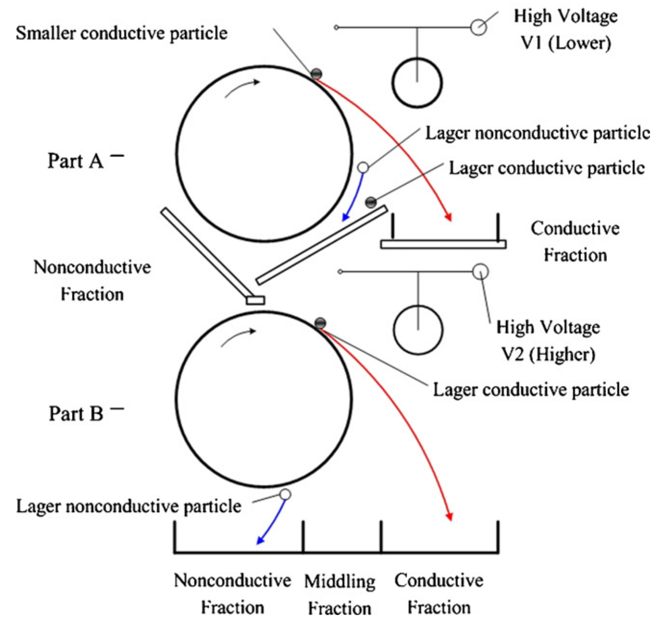

Fig. 5. Twice-step separation for multi-size granule mixture by using the two-roll separator.

5. Conclusion

For the separation of multi-size granule mixture from crushed PCB wastes, the classical roll-type electrostatic separator is up against a dilemma. It cannot effectively process such a granule mixture because of its sensitivity to the variation of particle size. In the present research, a new two-roll electrostatic separator was established for overcoming the limitation of the classical one and the progress was shown in:

1. The middling products strongly diminish (73% and 59% compared with groups 1 and 2, respectively) while the recovery of metals increases (34% and 22% compared with groups 1 and 2, respectively). The separation efficiency is sharply improved.
2. The metal component in the middling products notably decreases (only 33% compared with 58% for group 1 and 66% for group 2, respectively). This is very good for the recovery of metals.

3. The spark discharge and the impact of small particle onto the electrostatic electrode are successfully weakened by two fields with different intensity. This improves the stability and reliability of the separation system.
4. The two-roll electrostatic separator provides an effective and flexible method for separating multi-size granule mixture. In the present research, the particle size varies only from 0.091 to 1.2 mm because of the need for a good dissociation of metals and nonmetals. However, the effect will be more outstanding when the variation range of particle size is larger. It is significant for recycling crushed WEEE which always contains granule with different size.

Acknowledgements

This project was supported by the National High Technology Research and Development Program of China (863 program 2006AA06Z364), Program for New Century Excellent Talents in University and the Research Fund for the Doctoral Program of Higher Education (20060248058).

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