Energy 142 (2018) 191–195

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A novel pneumatic separator for separating diode and CD capacitance of waste printed circuit boards

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ARTICLE INFO

Article history:
Received 24 December 2015
Received in revised form
16 February 2017
Accepted 8 October 2017
Available online 10 October 2017

Keywords:
Electronic components
Metals recovery
Sustainability
Pneumatic separation

ABSTRACT

Waste printed circuit boards (WPCBs) contain abundant metals. Recovering WPCBs is significant in energy conservation, sustainable development, and environmental protection, which save the energy and environment cost of searching and melting of metals. Many reports were related to environment-friendly disposal of basal boards of WPCBs. Little information was reported about the recovery technology of electronic components. In this paper, a novel and pollution-free pneumatic separator was invented to separate diode (Ti enriched components) and CD capacitance (Sn enriched components). Trajectory models of diode and CD capacitance in pneumatic separation were established. Then, optimized parameters of airflow velocity (0.77 m/s) and position (0.16 m) of separation plate of pneumatic separation were obtained. Separation rates of diode and CD capacitances in pneumatic separation reached up to 96.7 wt% and 97.3 wt%. This paper provided an environment-friendly and high-efficiency separator for separating electronic components of WPCBs. The trajectory models also can guide pneumatic separation of other electronic components.

1. Introduction

Recover resource and energy from municipal solid waste is an important topic in sustainable development of the world [1,2]. E-waste has been considered as urban mining [3,4]. Recovering e-waste is a significant work in sustainability and energy renewable, which can save the energy cost of searching and smelting of metals [5]. Waste printed circuit boards (WPCBs), the core component of electronics products, were largely produced [6]. In China, the weight of WPCBs was about 170 thousand tons per year [7]. WPCBs contain lots of high purity metals (Cu, Zn, Ni, Sn, Ti, Ag, Au, et al.) and nonmetals (glass fiber, epoxy resin, and additives) [8,9]. At present, pollution of heavy metals and organics generated in situs of recovering WPCBs by employing crude technologies (e.g. acid washing and open incineration) [10–12]. Health of local residents was harmed [13,14]. Fortunately, environment-friendly technologies, such as electrostatic separation [15], bioleaching metallurgy [16,17], vacuum metallurgy [18], and recovering lines [19], have been developed for recovering metals from basal boards of WPCBs. WPCBs not only include basal boards but also consist of electronic components. Heated-air disassembling and selective desoldering separation were proposed to liberate electronic components from basal boards of WPCBs [20,21]. However, little information was reported about the separation of different electronic components. Different electronic components contain different metals and they needed to be further separated so as to improve the recovery efficiency of metals in post-processing (e.g. metallurgy) [22–24]. Screening was not suitable for the further separation. The reason is that the size ranges of electronic components are various.

In this paper, new pneumatic separator was designed to separate different electronic components. Trajectory models of diode (Ti enriched) and CD capacitance (Sn enriched) in pneumatic separation were established. The optimized parameters of airflow velocity and the position of separation plate of pneumatic separation were studied. This paper contributed an environment-friendly and high-efficiency separator to separate electronic components of WPCBs.

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https://doi.org/10.1016/j.energy.2017.10.034
0360-5442/

2. Material and methods

2.1. Materials

Electronic components of WPCBs of waste computers were manual dismantled in lab. Diode and CD capacitance were chosen for investigating their movement behaviors in pneumatic separation.

2.2. Designed pneumatic separator and experimental procedure

Pneumatic separator was self-designed and manufactured by collaboration with a licensed e-waste recovery enterprise. Pneumatic separator consisted of vibrator feeding, fan, separation cavity, separation plate (D), and two outlets (Fig. 1(a)). The entire system was closed for preventing dust diffusing to air. Vibrator was designed to keep electronic components in sequence when fed into separation cavity. Fan provided horizontal airflow (v) for pneumatic separation. Separation plate (D) was placed in the cavity for separating the different electronic components. The position of plate (D) could be adjusted in horizontal direction.

Experiments of pneumatic separation were performed in the licensed factory of disposing e-waste (Yangzhou Ningda Noble Metal CO., LTD) in Jiangsu province of China. Pneumatic separator was employed to separate diodes and CD capacitances. The mixed diodes and CD capacitances were fed into pneumatic separator monolayer by the vibrator. The fan provided the airflow to cause different horizontal displacement (x) of diodes and CD capacitances and separate them. The width of the airflow passage was y. The separation rate of diodes and CD capacitances was determined by the velocity (v) of airflow and the position of separation plate (D). Trajectory models of diodes and CD capacitances in pneumatic separation were studied and optimized parameters of wind velocity and separation plate position were investigated in following parts.

2.3. Trajectory models of diode and CD capacitance in vertical direction of pneumatic separation

In vertical direction of pneumatic separation, due to no forward airflow, the airflow was considered as laminar region. Electronic component subjected to gravity force (G), air buoyancy force (T), and air resistance (F_d) (Fig. 1(b)). Due to the small values of density of airflow (1.29 kg/m^3) and volume of electronic components, air buoyancy force was neglected. Thus, co-acting force of electronic component in vertical direction was expressed as:

$$F_y = mg - F_d \tag{1}$$

Where m is the mass of electronic component, g is the acceleration of gravity force. Meanwhile, air resistance was expressed as:

$$F_d = 3\pi d_p \mu u_y \tag{2}$$

$$d_p = \sqrt[3]{\frac{6V}{\pi}} \tag{3}$$

Where d_p is the equivalent volume diameter of electronic component, μ is the viscosity of the airflow in normal pressure (1.81×10^{-5} Pa s), u_y is the velocity of electronic component in vertical direction. Acceleration of co-acting force in vertical direction was computed as:

$$\frac{du_y}{dt_y} = \frac{mg - 3\pi d_p \mu u_y}{m} \tag{4}$$

Where t_y is the motion time in vertical direction of airflow. After indefinite integral, t_y was computed as:

$$t_y = -\frac{m}{\pi d_p \mu} \ln\left| g - \frac{\pi d_p \mu}{m} u_y \right| + C \tag{5}$$

$$C = \frac{m}{\pi d_p \mu} \ln g \tag{6}$$

Due to gravity force was greater than air resistance, equation for the relationship of t_y and u_y was:

$$t_y = \frac{m}{\pi d_p \mu} \ln \frac{mg}{mg - \pi d_p \mu u_y} \tag{7}$$

Thus, equation for the relationship between vertical displacement (y) and t_y can be expressed as:

$$y = \frac{mgt_y}{\pi d_p \mu} - \frac{mgt_y}{\pi d_p \mu e^{\frac{\pi d_p \mu t_y}{m}}} \tag{8}$$

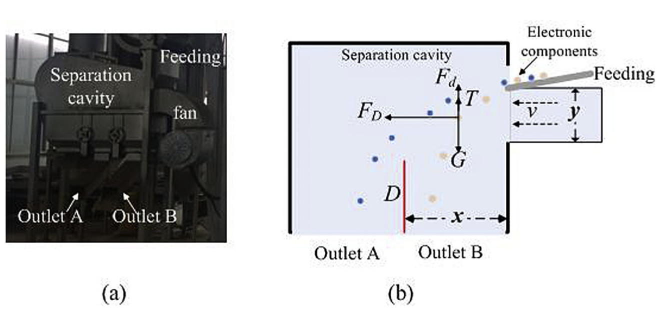

Fig. 1. (a) Pneumatic separator, (b) inner structure of pneumatic separator and force analysis of pneumatic separation.

2.4. Trajectory models of diode and CD capacitance in horizontal direction of pneumatic separation

Diode and CD capacitance were fed into the separation cavity slowly in order to keep horizontal velocity at 0 approximately. Airflow velocity (v) was provided by the fan. In horizontal direction, diode and CD capacitance subjected to aerodynamic force (F_D), which was the resultant force of air pressure and frictional resistance. The air pressure was explained by the Total Flow Bernoulli Equation [25] and Fig. 2.

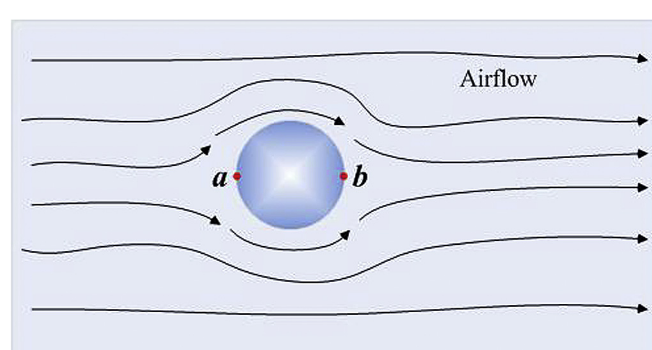

Fig. 2. Generation of air pressure of diode could and CD capacitance of WPCBs moved in airflow.