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Recycling oriented vertical vibratory separation of copper and polypropylene particles

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ABSTRACT

Vibration has been employed in various engineering processes for material handling. The famous Brazil nut effect, large particles tend to rise to the top under vibration, initiates various research about vibration induced particle segregation. Particle size and density are two determining factors for their behavior under vibration. Previous research in University of Nottingham proves vertical vibratory separation to be a promising environmental friendly mechanical separation method for recycling metallic fraction from shredded Waste Electric and Electronic Equipment (WEEE) stream. A pilot scale thin cell vibratory separator has been developed to investigate the potential for WEEE recycling applications. Shredded copper and polypropylene particles have been chosen to mimic metallic and non-metallic fractions in WEEE. Vibratory separation experiment with controlled environment and addition of solid lubricant are presented in this paper. The result demonstrates the effect of relative humidity and solid lubricant on improving flowability of granular system hence successful vibratory separation. The proposed mechanisms for the presence of moisture and solid lubricant are lubricant effect and elimination of static electricity.

1. Introduction

Increasing concern has revolved around the issue of Waste Electric and Electronic Equipment (WEEE) recycling around the world. It is estimated that 315 million computers has be discarded between 1997 and 2004 [1]. Global WEEE generation is estimated to be 20–25 million tonnes per year [2]. WEEE recycling has posed a great challenge to China, which is the destination for over 70% of WEEE worldwide [3,4]. The current approach of WEEE recycling is predominately acid leaching [5–8] and open incineration in remote areas in developing countries [9,10]. Serious environmental and health problems induced by WEEE recycling have been reported in the famous WEEE recycling town, Guiyu [3,11]. Chemical methods such as strong acid leaching and open incineration are practiced in this town for decades for WEEE recycling, which has caused soil, water and air pollution. Nephrolith and some respiratory problem become common local diseases and no portable water could be found within 10 km from this town [12]. From resource and economic points of view, WEEE can be regarded as source of precious metals. A life cycle assessment report for metal recovery from high-grade WEEE stated the recovery of 165 kg copper and precious metal, 381 kg iron and 22 kg aluminium from 1000 kg of high-grade WEEE [5]. Widmer et al. claimed that early generation PCs each contain up to 4 g of gold and 1 g for current generation PCs [13].

Originated from 'Brazil nut effect', the phenomena of vibration-induced segregation of granular material had attracted attention from numerous researchers to investigate the behavior pattern of particles subjected to vertical vibration [14–18]. Vibration condition, separation cell geometry and properties of particles are three major factors influencing the particle separation efficiency [19,20]. The application of vibratory separation on waste recycling proves its potential in metal recovery from WEEE, especially Printed Wiring Boards (PWBs). The development of a novel dry separation system for WEEE recycling could significantly reduce the amount of energy and chemical consumption as well as environmental impact. Mohabuth et al. [21] developed a lab scale two-chamber partition cell and proved the capability to concentrate metal elements from waste electrical cables and PWBs in different size fractions from 105–300 μm. The system was then modified by Habib et al. [22] to T-shape separation cell for the separation of metallic fractions from shredded PWBs particles less than 1.5 mm. Both systems have proved the effectiveness of vibratory separation for the recovery of metallic fraction from shredded WEEE. However, the separation processes of both systems were very slow (about 45 min) and limited their scale-up development for industrial application.

The research presented in this paper aims at providing experimental basis for developing a fast vertical vibratory separation system for WEEE recycling. The thin cell design used for vibratory separation of bronze

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and glass spheres has been reappraised [23]. Successful separation experiment presented in this study finish within 2 min, single thin cell separation cell can be expanded to multi-cell design for industrial scale-up still maintain the same separation time. Copper and polypropylene particle samples have been prepared to represent the metallic and non-metallic fractions in shredded PWBs respectively. Two sets of experiment with controlled environment and addition of solid lubricant has been designed to investigate the effect of water and glidant on separation mechanisms. Experimental results illustrate that success of separation is related to the presence of water and solid lubrication in the granular system. The outcome of this experiment improves the understanding of the influence of flowability of granular system on vibration induced particle separation and provides a possible solution for enhanced vibratory separation.

2. Experimental methodology

2.1. Vertical vibration system

To understand the separation mechanisms and investigate the optimal separation parameters (vibration intensity, frequency, separation cell geometry) for WEEE recycling oriented operation, a novel vibratory separation rig has been developed as shown in Fig. 1. The vibration system in this rig consists of two carbon steel plates, the bottom plate sits on the metallic frame with poles and springs fixed at four corners, which nest to ball bearings and spring holders on the vibration plate. Vibtec-FP-95 pneumatic linear vibrator was bolted to the bottom of the vibration plate to provide vibratory force. Freescale MMA2241KEG single axis accelerometer with acceleration range of ± 10 g (g = gravitational acceleration) is installed on the top vibration plate to monitor the vibrational acceleration and frequency. Separation cell design from Webster [23] has been reappraised and thin depth with slopped base has been adopted to accelerate the separation process. The base block of the separation cell is made from polyoxymethylene with 15° slope and two height-adjustable weirs at both ends. Perspex plates are used for separation cell for visual observation to identify separation. The thickness of the block is 50 mm and another piece of perspex can be inserted to adjust the depth of separation cell. The depth of separation cell used in this study is 10 mm. The length of the separation cell is 200 mm and the height can be altered via adjustable weirs between 10 mm and 100 mm. Silica glue is used to seal the connection among different parts. (See Fig. 2.)

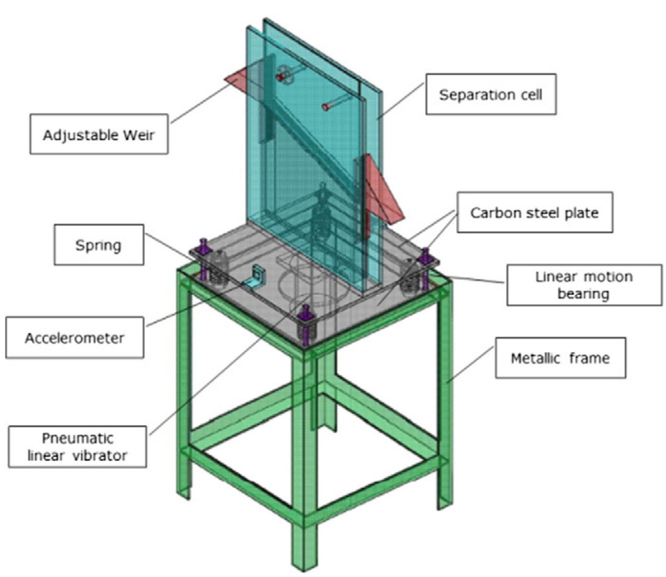

Fig. 1. The design of a novel vibratory separator.

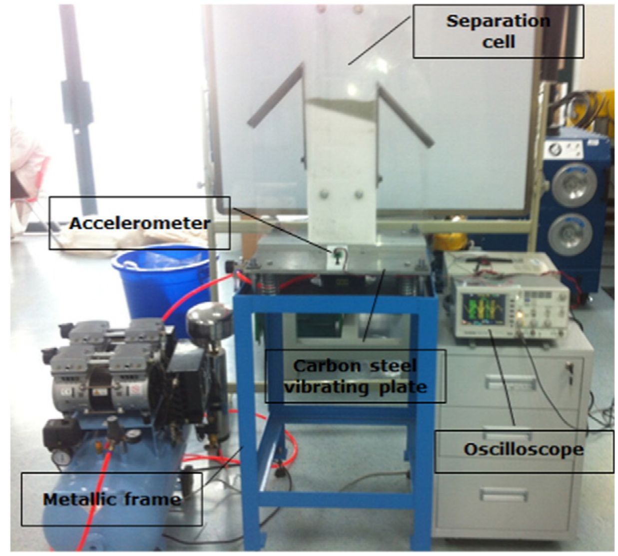

Fig. 2. The novel vibratory separator.

The vibration condition is described by two parameters: dimensionless vibration intensity parameter Γ and vibration frequency f.

$$\Gamma = A\omega^2/g$$

where A is the amplitude of vibration, angular frequency $\omega = 2\pi f$, and g is gravitational acceleration.

2.2. Sample preparation

Artificial samples have been prepared to investigate the vibration-induced separation behavior of granular system. Copper and polypropylene were selected to represent the metallic and non-metallic fractions in WEEE respectively. To determine the optimum particle size that can be achieved under room temperature condition, two stage grinding with Fengli CSF570 hammer mill and Retsch SM2000 cutting mill (Fig. 3) have been applied to process waste computer

Fig. 3. Instrument for size reduction. (left: Retsch SM 2000; right: Fengli CSF570).