Journal of Cleaner Production 165 (2017) 452–457

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Metals recovery from dust derived from recycling line of waste printed circuit boards

Fangfang Wang [a], Yuemin Zhao [a, b, *], Tao Zhang [c], Guangwen Zhang [b], Xing Yang [b], Yaqun He [b, c], Lizhang Wang [a], Chenlong Duan [b]

[a] School of Environment Science and Spatial Informatics, China University of Mining and Technology, Xuzhou 221116, China
[b] School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, China
[c] Advanced Analysis and Computation Center, China University of Mining and Technology, Xuzhou 221116, China

ARTICLE INFO

Article history:
Received 18 February 2017
Received in revised form
6 July 2017
Accepted 15 July 2017
Available online 17 July 2017

Keywords:
Vibrated gas-solid fluidized bed
Waste printed circuit board
Dust
Fiberglass
Recycling

ABSTRACT

Dust is an indispensable byproduct in the physical-mechanical recycling process of waste printed circuit boards. It is in urgent need for recycling valuable materials from dust because of high economic value and serious pollution. In this study, a novel technology of vibrated gas-solid fluidized bed was proposed to recover metals from dust with a size fraction of −0.5 mm. Firstly, the mineralogical properties were analyzed by advanced analysis technologies, and then the triboelectric separation was applied to remove glass fibers from dust to eliminate the effect of agglomeration that was caused by glass fibers in the process of density-segregation. The results demonstrated that the major metal elements were Fe, Cu, Mn, Zn and Mg, and the content of metals accounted for 18.865 wt.% in −0.5 mm size fraction of dust. The metal content increased to 21.852 wt.% after removing glass fibers. The metal recovery rate was up to 78.77%, which demonstrated that the vibrated gas-solid fluidized bed had obvious recovery efficiency for metals from dust. This research work may provide an alternative approach for industrial recycling WPCBs dust, and reduce the secondary waste generated in PCBs recycling.

1. Introduction

With the rapid development of electronic industry, printed circuit boards as fundamental products develop very fast. In recent years, waste electrical and electronic equipment (WEEE) present a rapid growth trend because of high performance requirement and frequent upgrade of electrical and electronic equipment. Recycling waste printed circuit boards (WPCBs) is a thorny problem in the disposal process of WEEE because of the high levels of hazardous substances and complex structures. WPCBs also contain large amounts of metals, such as copper, iron, nickel, chromium, lead, etc., which not only have serious pollution but also high economic value (Yamane et al., 2011; Huang et al., 2009; Li et al., 2007a). Except for metals, WPCBs contain a lot of nonmetals, such as epoxy resin, glass fibers and other plastics (Silvas et al., 2015). Proper WPCBs recycling is quite necessary from the viewpoint of environmental protection and economic value.

Because of high economic value, recycling metals from WPCBs has attracted increased attention. A series of sophisticated technologies have been developed. Chemical and physical-mechanical methods are useful technologies for recycling WPCBs, and they have been studied by many scholars. Both vacuum pyrolysis and leaching are high-efficiency chemical method (Li et al., 2010; Jha et al., 2012; Huang et al., 2014), while physical-mechanical methods include gravity separation (Yoo et al., 2009; Duan et al., 2015), electronic separation (Li et al., 2007b; Wu et al., 2009) and magnetic separation. As an efficient physical-mechanical method, corona electronic separation has realized its industrial application because of its high efficiency, good operability and space saving. In this recycling process, WPCBs have been crushed first, and then the mixture of metals and nonmetals is placed into corona electronic separator for separation. Afterwards, the metals will be reused after purification. For nonmetals, a novel technology of being used as filler to produce composite has been proved to be a useful method to reuse them. The nonmetal powder was used as admixture in cement mortar by Wang et al. (2012). Guo et al. made wood plastic composite material using nonmetal fraction as filler (Guo et al., 2010). Zheng et al. studied on the reuse of nonmetals as

* Corresponding author. School of Chemical Engineering and Technology, China University of Mining and Technology, Xuzhou 221116, Jiangsu, China.
E-mail address: ymzhao_cumt@126.com (Y. Zhao).

http://dx.doi.org/10.1016/j.jclepro.2017.07.112
0959-6526/

reinforcing filler in the polypropylene composites (Zheng et al., 2009). Zhang et al. studied on removing inorganics from non-metals, and they found that removing inorganics can strengthen the mechanical strength of composite (Zhang et al., 2017a).

However, another byproduct, dust is also produced in the physical-mechanical recycling process. In the process of crushing, sieving, air float table separation, a large amount of dust is produced, and its content is up to about 3.7% of its capacity. The mineralogical characters of dust collected from typical recycling line of waste printed circuit boards has been analyzed by Wang et al., they found that the dust was mainly composed of Al, Cu, Fe, Si Ca and Pb apart from 73.1 wt.% organic materials (Wang et al., 2015). There are also some trace elements, such as Na, Mg, Mn, Zn, Ag and Sn. The serious pollution will be caused by the high content of heavy metals and halogenated flame retardants in dust if it is not managed properly.

Vibration gas-solid fluidized bed, as a physical separation method based on different density, has been studied by many scholars. The vibration is introduced to strengthen the gravity segregation of fine particles. Yang et al. studied on processing fine coal by VGFB, and they found that a VGFB was useful to coal preparation in drought and cold regions, especially for fine coal cleaning (Yang et al., 2013, 2015). Obvious density difference is presented between metals and nonmetals, which provide basis for their gravity separation.

In this study, the size distribution of dust was analyzed by sieving, and then −0.5 mm size fraction was adopted as the research object because of high metal content. The chemical composition and morphology were analyzed by modern analysis methods. A novel technology of vibration gas-solid fluidized bed was proposed to recover metals from the dust. In addition, the triboelectric separation was introduced to remove glass fibers and strengthen the process of gravity segregation by evanishing agglomerate in the fluidized bed. After separation, the segregation performance and distribution characteristics of metals were analyzed.

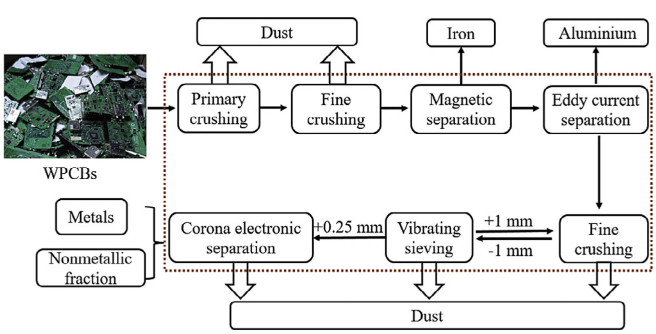

Fig. 1. The processing flowsheet of waste printed circuit boards in physical-mechanical recycling line.

2. Experimental

2.1. Sample preparation

The sample is collected from an industrial physical-mechanical recycling line of WPCBs in Anhui province, China. Crushing is a necessary step in the physical-mechanical recycling process of WPCBs. WPCBs (including components) are first primary-crushed, and then through fine-crushed by impact crusher. Iron is removed by magnetic separators, while eddy current separation is used to enrich the non-ferrous metals (mainly aluminum). The eddy current nonmetallic materials are placed into a crusher for tertiary crushing, sieved through mesh, and materials with a size fraction of −1 mm will be given into the corona electrostatic separator from the machine. Metals and nonmetals will be obtained from this recycling line. Materials with a size fraction +1 mm will be recycled into the third stage crushing, until broken into −1 mm or less, then into the electrostatic separator for sorting.

The dust is an unavoidable byproduct in physical-mechanical recycling line, as shown in Fig. 1, and it is produced in the processes of crushing, sieving and separation. Dust collection is widely distributed in each step of this recycling line. Because of high content of heavy metals and plastics, recycling dust should be given more attention from the prospective of resource recycling and environmental protection.

In each processing step, the cyclone is used to collect WPCPs dust. The dust has been sieved into six fractions, as shown in Fig. 2, and they are +1 mm, −1+0.5 mm, −0.5 + 0.25 mm, −0.25 + 0.125 mm, −0.125 + 0.075 mm and −0.075 mm size fractions. In this physical-mechanical recycling line, the electronic components (capacitors, resistors, and transformer) are not dismantled before crushing, which results in that the complex dust is obtained. The main components of +1 mm size fraction are diaphragms from capacitors. In −1+0.5 mm size fractions, the main components are diaphragms from capacitors, flocks and some unbroken WPCBs. For fine size fractions (−0.5 mm size fractions), there are many plastics, glass fibers, flocks and metals in them. The diaphragms and flocks are mainly collected in larger size fraction because of strong

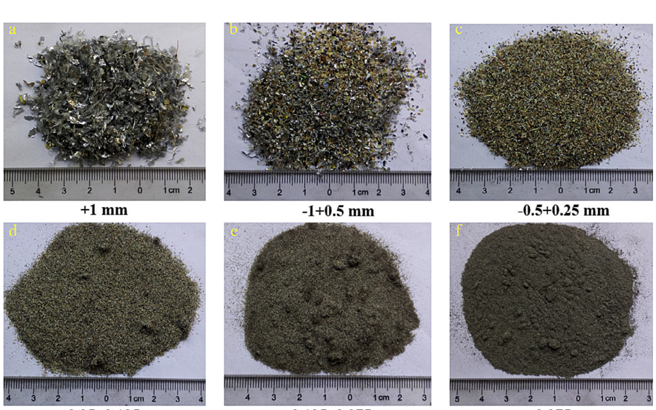

Fig. 2. The dust collected from physical-mechanical recycling line.

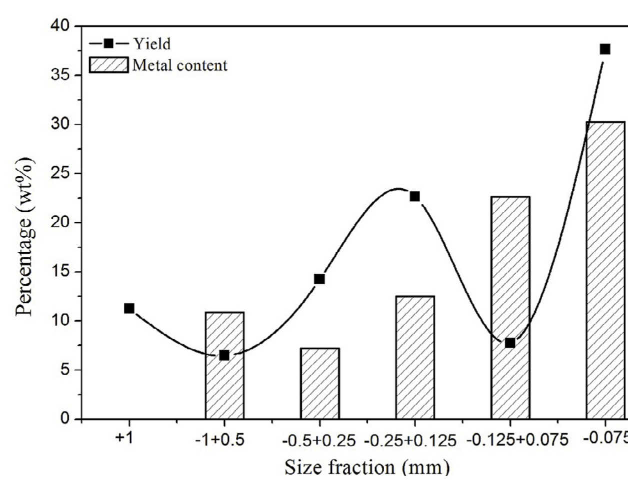

Fig. 3. The yield of each size fraction.