Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Review

Recycling of indium from waste LCD: A promising non-crushing leaching with the aid of ultrasonic wave

Kaihua Zhang [a], Bin Li [a], Yufeng Wu [a,*], Wei Wang [a], Rubing Li [a], Yinan Zhang [b], Tieyong Zuo [a]

[a] Institute of Circular Economy, Beijing University of Technology, Beijing 100124, PR China
[b] Institute of Biomaterials and Biomedical Engineering, University of Toronto, Toronto, ON M5S 3G9, Canada

ARTICLE INFO

Article history:
Received 21 December 2016
Revised 17 March 2017
Accepted 19 March 2017
Available online xxxx

Keywords:
Waste liquid crystal display (LCD)
Indium
Ultrasonic wave

ABSTRACT

The tremendous amount of end-of-life liquid crystal displays (LCDs) has become one of the prominent sources of waste electrical and electronic equipment (WEEE) in recent years. Despite the necessity of safe treatment, recycling indium is also a focus of waste LCD treatment because of the scarcity of indium. Based on the analyses of the structure of Indium Tin Oxide (ITO) glass, crushing is demonstrated to be not required. In the present research, a complete non-crushing leaching method was firstly adopted to recycle indium from waste LCDs, and the ultrasonic waves was applied in the leaching process. The results demonstrated that indium can be leached efficiently with even a low concentration of chloride acid (HCl) without extra heating. About 96.80% can be recovered in 60 mins, when the ITO glass was leached by 0.8 M HCl with an enhancement of 300 W ultrasonic waves. The indium leaching process is abridged free from crushing, and proves to be of higher efficiency. In addition, the ultrasonic wave influence on leaching process was also explained combing with micron-scale structure of ITO glass.

Contents

* Corresponding author at: No. 100, Pingleyuan Street, Chaoyang District, Beijing 100124, China.
E-mail address: wuyufeng3r@126.com (Y. Wu).

http://dx.doi.org/10.1016/j.wasman.2017.03.031
0956-053X/© 2017 Published by Elsevier Ltd.

1. Introduction

Indium is known as a scarce metal because of its extremely low concentration in the crust of earth (merely less than 200 ppb) (Alfantazi and Moskalyk, 2003); despite the scarcity of indium, its compounds have been applied comprehensively because of their favorable semi-conductive and optoelectronic performances. In particular, indium oxide combined with tin oxide (at an approximate mass ratio of 9:1) can be employed to produce the Indium Tin Oxide (ITO) films used in liquid crystal display (LCD) panels; this application accounts for nearly 80% of the total consumption of indium (Park et al., 2009). Because of the lack of independent indium ores, the world-wide indium production primarily depends on the by-product of Sphalerite and lead mineral ores, especially in China (Frenzel et al., 2016; Gupta et al., 2004; Zhang et al., 2016). Moreover, driven by the growing LCD market, the increasing indium demand further provides a challenge for the sustainable application of indium deposits. The recycling of secondary resources of indium would be an effective approach to mitigate the exhaustion of the primary minerals of indium. Furthermore, the low grade (featuring indium content as low as 0.002%) of raw ores that are considered to be worthy of smelting (Kumar et al., 2013) also makes them less satisfactory resources compared with indium-containing wastes. In fact, the end-of-life LCD monitors have prospects of being a reliable resource for indium production, given their indium concentration and colossal amounts. The indium content of end-of-life LCD monitors exceeds that of the primary ores, with the indium concentration covering a range from 102 mg/kg to 968.5 mg/kg for the various LCD display processing techniques of different companies (Dodbiba et al., 2012;Yang et al., 2013; Savvilotidou et al., 2015). Moreover, the massive number of waste LCD electronic products, including TVs, computers and laptops, has accumulated to become an enormous amount of waste material. According to the Chinese Statistical Yearbook of the Electronic Information Industry (2004–2012), approximately 9500 million of LCD monitors were sold in China between 2005 and 2010. With an average lifespan of 5–6 years, the useful electronic appliances inevitably reach their end-of-life state and are transformed into hazardous wastes (Schmidt, 2005). Furthermore, because of the cytotoxicity of soluble ITO to our respiratory system, the proper disposition of waste LCD monitors and indium recycling is necessary to avoid the adverse environmental influence of indium (Chou and Huang, 2009;Lim and Schoenung, 2010). Instead of being tackled as merely wastes, these end-of-life LCD products could also be a reliable potential indium resource, covering about half of the total indium demand in 2035 (Wang et al., 2015).

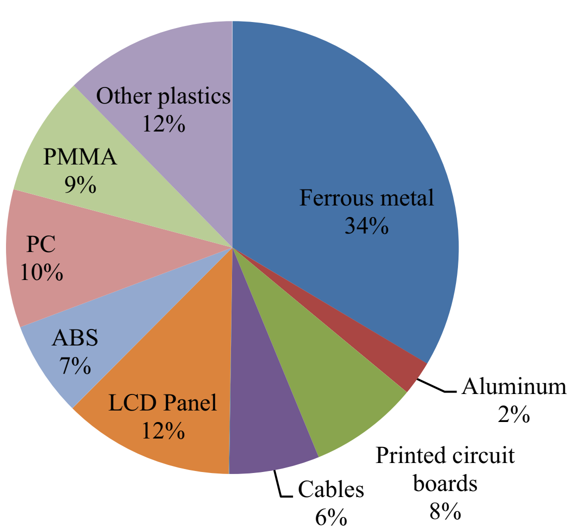

Fig. 1. The main composition and proportion of a computer monitor in terms of mass.

1.1. Disposal status quo of LCD fragments

The current disposal of used LCDs including incineration and landfill, is not only a waste of potential resources, but also brings in tremendous environment risks (Kolias et al., 2014; Kiddee et al., 2013). In fact, different parts in a certain monitor can be used with proper methods. Taken one unit of waste LCD display for example, the composition and individual components are shown in Fig. 1.

1.2. Characterization of the LCD samples

In the existing research studies concerning indium recycling from waste LCDs, hydrometallurgy involving leaching and extraction has been the most common method used. Because the appropriate extractant (P204, Cyanex923, PC88A) and techniques for leaching are well established in the massive indium production industry (Gupta et al., 2004; Jinhui et al., 2012;Kang et al., 2013), leaching can be the foremost step to recycle indium effectively from waste LCD. To liberate ITO efficiently and facilitate the subsequent leaching among the glass particles with acid, the mainstreams of research studies inevitably involved various crushing methods and applicable tools hammer (Hasegawa et al., 2013), ball mills (Rocchetti et al., 2015) and even high-energy ball milling (Lee et al., 2013) and explored the crushing time and optimum particle sizes (Ghosh et al., 2009).

However, some confusing aspects were also revealed among the available research studies. As shown in Table 1, the optimum size, directly related to the maximum recovery percentages, varied over a great span: from 10 μm to 5 mm; thus, these sizes appear to be too inaccurate to be legitimate. Besides, some researchers have reported that excessive grinding may cause indium loss (Rocchetti and Beolchini, 2015). Considering ITO layer to be reported as thin as 125 nm, a non-crushing way is proposed in the paper, and ultrasonic wave were applied to improve leaching efficiency (Li et al., 2009). Moreover, It had been report recently to leach indium from ITO glass without crushing as ITO layer is on the present side (Fontana et al., 2015). Without involving crushing, the entire leaching process can be simplified to free from filtering, and thus to be appropriate for industrial application.

The use of ultrasonic waves has gradually become a practical method to facilitate waste recycling, primarily for sludge and other organic samples (Álvarez Sánchez et al., 2008;Wang et al., 2010). For example, Huang et al. (2011) reported the recovery of copper (Cu) and iron (Fe) from the generated sludge of waste Printed Circuit Boards (PCBs) production. With the enhancement of ultrasonic wave energy, the recycling process of Fe and Cu proved to be more cost-efficient and consume a smaller amount of chemicals (Huang et al., 2011). Li et al. (2014) applied organic acid to the leaching of cobalt (Co) and lithium (Li) from the cathode active materials of spent Lithium-ion Batteries, the ultrasonic-assisted leaching method is demonstrated to be environmentally friendly and to leach both Li and Co efficiently (Li et al., 2014).

The paper aims to propose a non-crushing leaching method for efficient recycling of indium from waste LCDs. Considering the structure of waste LCD glass, the misconceptions about the necessity of crushing are explained. With the aid of ultrasonic waves, high-efficiency indium leaching can be attained with a low concentration of HCl and without extra heating. Different parameters that are crucial to indium leaching, including concentration of HCl, leaching time, and power of ultrasonic power, were all considered, and the appropriate leaching condition was obtained accordingly.

Please cite this article in press as: Zhang, K., et al. Recycling of indium from waste LCD: A promising non-crushing leaching with the aid of ultrasonic wave. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.03.031