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Beneficiation of cobalt, copper and aluminum from wasted lithium-ion batteries by mechanical processing

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ABSTRACT

Lithium-ion batteries are widely used as a power source for portable equipment. In the present work a sample of batteries was submitted to a series of mechanical processes to recover cobalt, copper and aluminum. The initial milling process promoted a previous particle distribution of the metal content fractions. Each of these fractions underwent to the most suitable recovery process according to their composition, especially regarding the presence of copper and magnetic metals such as iron and cobalt. The magnetic separation was efficient for particle sizes from 1 mm to 2 mm, resulting in a concentrate with up to 54% copper. The gravimetric separation with a Wilfley table, performed on the fraction with lower concentration of magnetic metals, resulted in a concentrate with up to 66% copper. Cobalt is found mainly in the fine material with particle sizes smaller than 1 mm. Quantitative chemical analysis has shown promising results when the concentrate is leached, with the cobalt concentration corresponding to 80% of the dissolved elements. The results demonstrate that it is possible to obtain rich concentrates of cobalt and copper through mechanical processing of lithium-ion batteries, and that it is feasible to concentrate aluminum as a by-product by applying additional mechanical processes.

1. Introduction

The world production of LIBs (lithium-ion batteries) in 2000 reached 500 million units and nearly 4.6 billion in 2010 (UMICORE, 2013a). These batteries have substituted Ni–Cd and Ni–MH batteries in most portable applications due to their high energy density, low auto-discharge rate, absence of memory effect and excellent life cycle. Therefore, the increasing demand for portable devices, such as mobile phones, microcomputers and digital cameras, has contributed directly to the rise in consumption of LIBs (Freitas and Garcia, 2007). The European Guideline 2006/66/EC aims to minimize the environmental impact of both the productive process and the end-of-life practices regarding batteries, and, in the next years, several goals must be achieved with respect to their collection and recycling. In particular, 45% of spent batteries must be collected by September 2016 (Official Journal of the European Union, 2006).

In addition to these environmental demands, these batteries are a rich source of metals of great commercial interest. Around 36% of the battery's metal compositions is cobalt. Lithium corresponds to about 6% of its metal content. Additionally, these batteries contain around 13% copper and 9.5% aluminum (Mantuano et al., 2006).

As a consequence, many studies have been conducted recently addressing the development of environmentally sound processes for battery recycling (Briffaerts et al., 2009; Kawakami, 1999; Zhang et al., 1998; Pietrelli et al., 2002; Lain, 2001; Ra and Han, 2006; Mishra et al., 2008; Worrell and Reuter, 2014; Gasser and Aly, 2013), using varied routes, which can be either physical or chemical processes (Xu et al., 2008). Hydrometallurgical processes were developed to recover base metals (Mantuano, 2006) and to obtain lithium carbonate (Li_2CO_3) (Mclaughlin, 1994; McLaughlin and Adams, 1999; RECUPYL, 2013; Wang and Friedrich, 2015). Other research efforts were focused on pyrometallurgical methods to recover cobalt, nickel and iron (Saeki et al., 2004; Cardarelli and Dube, 2007; Georgi-Maschler et al., 2012). Many studies are also being conducted regarding the simultaneous recycling of mixed types of batteries (Georgi-Maschler et al., 2012; Granata et al., 2012; Nan et al., 2006).

The most recently developed processes for recycling LIB tend to combine different routes and techniques in order to reach a better product and optimize environmental performance. Umicore uses a hydro-pyrometallurgical process designed for both LIB and NiMH battery recycling, where cobalt and nickel are recovered as $Co(OH)_2/CoCl_2$ and $Ni(OH)_2$, respectively, and copper, zinc, manganese, and iron are recovered in aqueous solution, while carbon and organic material are burned and used as reducing agents (UMICORE, 2013b). The IME process consists of manually sorting and dismantling LIB to remove the outer case and electric components, and, after a series of mechanical processes (crushing, sieving, magnetic separation, and zigzag classifier), the fine fraction is pelletized and pyrometallurgically treated, while the flue dust and the slag are leached with sulfuric acid to produce lithium carbonate (Georgi-Maschler et al., 2012).

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Table 1
Composition, number of batteries and total weight of lots 1, 2 and 3.

Lot	Number of batteries	Batteries brands	Total weight (g)	Feeding flow rate (g/min)
Lot 1	185	Motorola	2720.3	187.6
Lot 2	155	Nokia	2370.1	239.4
Lot 3	180	80 Motorola 50 Nokia 20 Siemens 15 Samsung 15 LG	3331.4	241.4

Although there have been many research advances in the recycling technologies of LIBs, the development of efficient methods to recover the valuable metals present in their composition, such as cobalt, copper and aluminum, remains an important challenge for a sustainable world due to its environmental pressure and economic advantages. Physical processes, or mechanical treatment, are always required since metals in batteries are encapsulated in plastic or iron shells (Granata et al., 2012). They are usually applied as a pre-treatment to treat the outer

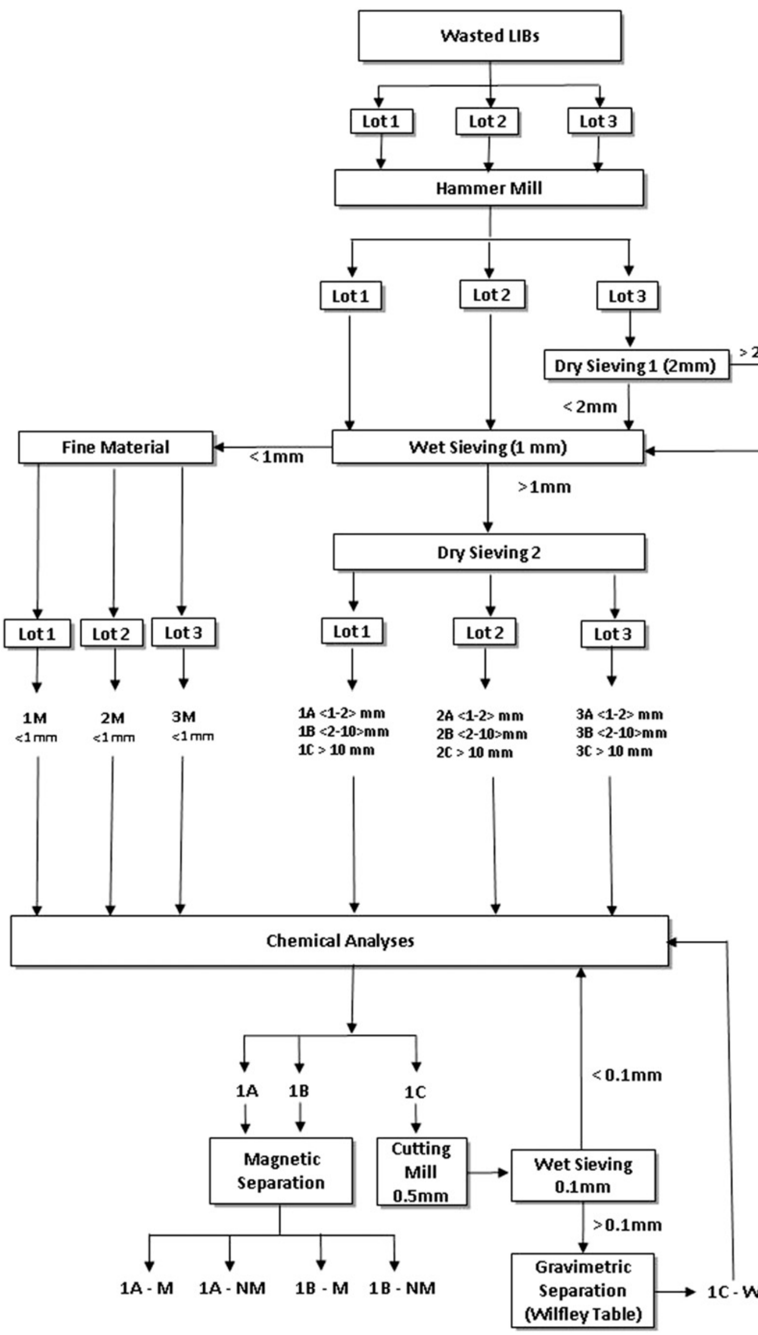

Fig. 1. Flowchart of processes followed in battery lots 1, 2 and 3.