RECYCLING OF END-OF-LIFE LIQUID CRYSTAL DISPLAYS: MATERIALS ASSESSMENT AND INDIUM RECOVERY

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ABSTRACT

Liquid crystal displays (LCD’s) are getting increased importance in flows of waste of electric and electronic equipment, for environmental, economic and strategic reasons. This work presents some results of a research carried out on the characterization of the constituting materials and the assessment of feasibility of indium recovery from the LCD-glass component by leaching. Metallic plates, plastics and printed circuit boards are the main components of monitors, and the LCD-glass only represents near 8%. Leaching of indium with low concentrated H₂SO₄ solutions was successfully attained, which seems to be a good option for its metallurgical recovery.

Keywords: recycling, liquid crystal displays, materials, leaching, indium.

INTRODUCTION

Liquid crystal displays are an emerging flow in waste of electric and electronic equipment (WEEE), requiring an adequate management aiming at valorizing the contained materials. For several years this type of monitors has successively replaced the classic cathode ray tube monitors in most applications. Nowadays LCD’s are used practically in all information technology devices which need a screen (mobile phones, tablets, TV’s, computers).

LCD screens have a wide range of components and materials, some very interesting in an economic point of view, e.g. printed circuit boards and indium-tin oxide (ITO) conductive film. Regarding indium, being a very scarce element and very important in some emerging technologies, its management is also a strategic issue. Other components have environmental issues such as the fluorescent lamps containing mercury. All of these factors are the driving force for developing efficient and environmentally safe recycling processes.

WEEE managers and processors are now dealing with increasing quantities of end-of-life LCD’s arriving to their systems and plants. Several studies on LCD recycling technologies are available (Alfantazi and Moskalyk, 2003; Ryan et al., 2011; Wang et al., 2013), but not yet completely settled for the treatment of these wastes. Different views about the best way of dealing with LCD’s subsist in both academic and industrial sectors. The two options are shredding and separating materials by mechanical/physical processing, or dismantling and processing separately the resulting components (see Fig. 1).

Besides dismantling and physical processing, in the metallurgical treatment there are also always two different approaches: pyrometallurgy and hydrometallurgy. When using pre-existing plants, furnace technology is usually easier to apply to wastes, although losses of
some important elements in the slag stream are often found. Hydrometallurgical technology is more versatile and can provide better solutions for low processing capacities. Some studies on the application of this type of treatments to LCD’s are available (Inoue and Alam, 2015; Kato et al., 2013; Li et al., 2011), but research on this domain is still scarce. For these devices, the glass component containing indium is sufficiently pure to anticipate a good opportunity for applying a hydrometallurgical approach.

In this paper, the characterization of LCD monitors is assessed through the mass balance of main components and materials. The recovery of indium from the LCD-glass fraction is also studied by leaching with diluted sulphuric acid solutions, aiming at evaluating the feasibility of a recovery process by hydrometallurgy.

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**EXPERIMENTAL**

Several LCD monitors (15 and 17”) used as peripheral of desktop computers were manually dismantled and the several components were separated, classified and weighted. The identification of several components and materials was performed which allowed to accomplish the respective mass balances. The LCD-glass component was separated and ground. Initially the samples were manually cut to plaques of about 150x120 mm and then shredded in a grab shredder (Erdwich EWZ 2000) using a discharge grid of 20 mm, resulting fragments with average particle size of 9 mm. A secondary grinding was therefore applied with a cutting mill (Retsch SM200) fitted with a discharge grid of 2 mm. The final solid material obtained, with average particle size of 0.60 mm, was sampled using a rotating divider to produce small samples for leaching tests and for analysis.

The concentration of indium in the LCD-glass component was assessed by Atomic Absorption Spectrometry (Thermoelemental 969AA) after digestion in a microwave oven with *aqua regia* (HCl/HNO₃ = 3/1 v/v). The average value found was 200 mg/kg In. The leaching experiments, using diluted H₂SO₄ solutions as leachant, were conducted in closed glass flasks with 200 mL capacity, stirred in a temperature controlled orbital shaker at 200 min⁻¹ velocity, for 1 h residence time. The liquid/solid ratio used was always 20 L/kg. Leaching yields were calculated from the determined In solution concentrations and were referred to the total In concentration in the initial solid material.
RESULTS AND DISCUSSION

Materials and Components Mass Balance

After the dismantling of the LCD monitors, the several components were separated and identified. The back structure and the base plate are constituted by polymeric materials (ABS, PS-HI, ABS+PC) with interior steel sheet reinforcement. The rear interior structure contains the printed circuit boards, usually three, which control all the monitor functionalities. The front panel or LCD-panel contains all the elements for generating the images, such as the reflector and diffuser sheets, the light distributor (made of perspex) and the LCD-glass component. The latter has two glass plaques, one being the thin-film transistor (TFT) glass with the ITO conductive device and the other the RGB glass for colour generation when lighted back. In the middle is the liquid crystal layer, which is a very thin layer of an organic substance. After separating the glass plaques, only small drops of this substance are perceptible.

The LCD technology is based on backlightning provided by two or more series of fluorescent or LED lamps located at the sides of the panel. The light is uniformly distributed by the entire glass surface through the perspex plaque. All the monitors analysed in this study were back lighted with fluorescent lamps (cold cathode fluorescent lamps, CCFL, the oldest technology). These devices are very small and thin, being easily broken when the dismantling is made without special care.

The mass balance of main components and materials is presented in Fig. 2. The distribution of components in the several monitors tested was not quite different from each other, independently from the size and the brand. The results show that metals (essentially steel and aluminium) represent 45% of the weight while polymers (only supports and frames, excluding films and plaques) contribute to 18%. Other components with relevance are the printed circuit boards (PCB’s) accounting to near 7%. PCB’s have a high copper content and also traces of precious and rare metals whose recycling is mandatory. LCD-glass plaques contribute to near 8% of the monitor’s weight.

![Fig. 2 - Average composition (wt%) of LCD monitors: (a) main parts, and (b) components/materials.](image-url)
Leaching of Indium from LCD-glass Component

The leaching studies were carried out to evaluate the efficiency of indium solubilisation, as the first step in the development of a hydrometallurgical process for recovery of indium in valuable form. The main objective was to perform leaching with the smallest consumption of reagents and energy. Within this assumption, two important factors arise as significant for evaluation, the temperature and the acid concentration. Fig. 3 shows the influence of these two factors on the indium leaching yields. Temperature effect is significant, allowing increasing the In yields from 26 to 92% when the temperature rises from 40 to 80°C, at constant concentration of H₂SO₄ (0.1 M). After 70°C, none improvement of yield was found. For the same temperature (70°C) and regarding the effect of acid concentration, Fig. 3b shows a slight increase in In solubilisation when increasing the concentration, being near 100% with 0.5 M H₂SO₄. Even using lower concentrations such as 0.1 M H₂SO₄, indium recoveries of near 100% were attained providing that higher residence times (e.g. 5h at 50°C) or higher temperature (e.g. 1h at 90°C) are used (data not presented in the Figures). These results show that the indium recovery from LCD waste by hydrometallurgical treatment can be achieved even using diluted acid.

![Fig. 3 - Leaching yields of indium from grinded LCD-glass component as a function of (a) temperature, and (b) H₂SO₄ concentration.](image)

Proposed Diagram for Recycling Indium

The results obtained in the experimental studies reported demonstrated that the hydrometallurgical processing of LCD-glass component of monitors can be an adequate alternative for indium recovery. Fig. 4 shows a proposed simplified diagram for processing LCD’s which shall be developed and optimized in future work. The monitors can be dismantled or directly processed as a whole. In case of dismantling, the different components are segregated and sent to specific processes according to each contained material. LCD-glass plaques are then ground and treated by hydrometallurgy (see dashed arrows in Figure). Alternatively, complete LCD monitors can be shredded and sieved in order to separate the fine fraction, containing the glass particles, from the gross fragments containing mostly of the other components (like steel, aluminium, plastics, PCB’s). Special care of gas emissions (potentially containing traces of mercury) shall be taken by applying efficient gas treatment
equipment. The coarse fraction produced can be processed using the usual physical separation plants for waste electronic devices, comprising magnetic separation, gravity separation and eddy-current separation, for producing the usual ferrous, non-ferrous and non-metal materials. The fines from the shredding separation are then sent to the hydrometallurgical plant.

The leaching of the LCD-glass particles with diluted acid leachant will allow the solubilisation of indium, separating this valuable metal from the insoluble glass material. The leachate can be then treated by hydrometallurgical operations for concentrating, purifying and recovering indium as a pure marketable form. Several purification/separation steps can be anticipated like solvent extraction, precipitation, reduction (e.g. cementation) aiming at improving the purity of indium in solution. These operations can be necessary since although the LCD-glass component is not rich in other metals, traces of some elements utilised in TFT device, in data/gate lines and in glass additives are surely found in solution, such as Cr, Mo, Al, Sr, As, Sb, thus requiring treatment. The final indium product (as metal, oxide or metal salt) can be subsequently generated from the purified solution.

**CONCLUSIONS**

The recycling of LCD monitors aiming at recovery of indium was assessed by leaching the LCD-glass component, after dismantling and grinding. The LCD-glass represent nearly 8% of the monitor weight, while the main materials identified were the metals (45%) and the plastics (18%). The printed circuit boards shall also be considered an important component for recycling due to the high valuable metal content. Regarding the LCD-glass treatment, the leaching with diluted H$_2$SO$_4$ solutions (e.g. 0.1 M) showed that high yields of In solubilization can be achieved, demonstrating that the indium recovery from LCD waste by hydrometallurgical treatment can be an adequate way for managing this important metal in this waste stream.

**REFERENCES**


