Holystic recycling of raw materials from waste liquid crystal displays screens of smartphones

Liliana M. Martelo[1], Márcia A. D. Silva[1,2], Hugo A. M. Bacelo[1], Margarida M. S. M. Bastos[2], Helena M. V. M. Soares[1*]

[1] REQUIMTE/LAQV, Departament of Chemical Engineering, Faculty of Engineering, University of Porto, Porto, 4200-465, Portugal
[2] LEPABE/ALICE, Departament of Chemical Engineering, Faculty of Engineering, University of Porto, Porto, 4200-465, Portugal

Keywords: Waste of LCD screen, Recycling hybrid process, Indium recovery, Liquid crystals recovery
* Presenting author email: hsoares@fe.up.pt

Liquid crystal displays (LCDs) from smartphones contain a diversity of bulk materials, such as: (i) indium (In), which is considered a strategic metal, (ii) glass and (iii) organic materials, such as liquid crystals (LCs), which are considered toxic and can be potentially recycled (Feng et al., 2022). In the LCD screen, these materials are organized as a sandwich structure (Figure 1), constituted by two types of glass substrate covered with the indium-tin oxide (ITO) substrate within the LCs between the glass and the polymeric film (PF). If not removed properly, the presence of PF prevents the reuse of glass (Zhao et al., 2013) and hinders the efficient recovery of indium (Houssaine Moutiy et al., 2020).

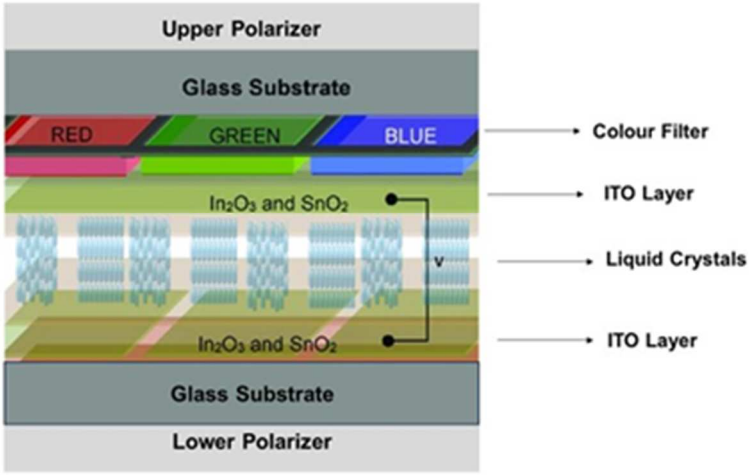

Figure 1. Schematic representation of the LCD screen. Adapted from (Yoshida et al., 2018).

Nowadays, the current recycling processes of LCDs screens consists of mechanical crushing or pyrolysis methods (Pereira et al., 2018; K. Zhang et al., 2017). However, the recovery rate of In is low and the toxic materials (LCs) and recyclable materials (In) are treated together when these methodologies are applied. Therefore, alternative methodologies that allow the delamination of the sandwich structure of the LCDs screens promoting the simultaneous PF removal and LCs dissolution is crucial for aiming the simultaneous and safe recovery of all main (indium, glass, plastic and LCs) raw materials of LCDs screens.

To accomplish these aims, a novel methodology, based on a four-step hybrid (physical plus chemical) process was developed for recycling individually all raw materials (indium, LCs, plastics, and glass) from LCD screens. Smartphones, collected from various brands and models, were, firstly, manually dismantled to isolate the LCDs screens and, then, the LCDs screens were mechanically cut into small pieces (16 cm^2). Simultaneous delamination of the cut LCDs screens and dissolution of the LCs was achieved using a polar mixture of 1.5 ethyl acetate and water using a low-pressure reactor at temperature of 180 ºC with a solid/liquid ratio of 70g/L. Subsequently, the layers containing mainly the ITO substrate (PF and glass substrate) were efficiently separated from the other layers (diffuse film and anti-reflecting layer) through wet gravimetric separation in aqueous solution as it can be seen in figure 2. Finally, high grade (97%) In was efficiently (84%) recovered from the ITO substrate after microwave-assisted acid leaching (0.25 M hydrochloric acid, S/L ratio of 20, 3 cycles of 30 s at 850 W) (with the simultaneous separation of glass and polymeric film) followed by ion-exchange technology using a byspicolamine resin.

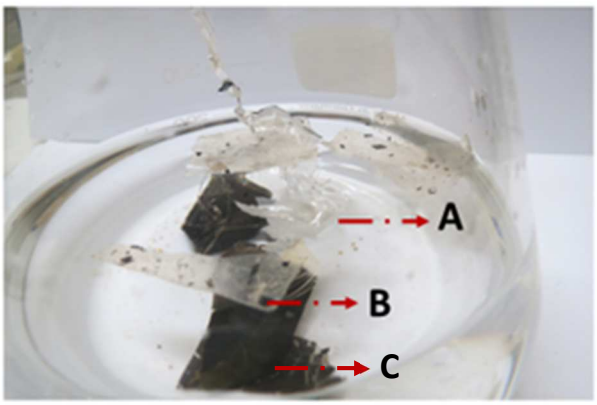

Figure 2. Wet gravimetric separation of the several layers of LCDs screens.
At the surface: **A** – the diffusive and **B**- the anti-reflecting film; At the bottom: **C** –the ITO substrate.

In conclusion, the LCD waste recycling strategy developed in this work constitutes an important breakthrough relatively to the existing treatment methods as it allows to recovery individually all main raw materials constitutive of LCDs screens, such as, In, glass and LCs.

References:

Feng, J.J., Sun, X.F., Zeng, E.Y., 2022. Emissions of Liquid Crystal Monomers from Obsolete Smartphone Screens in Indoor Settings: Characteristics and Human Exposure Risk. Environ Sci Technol 56, 8053–8060. https://doi.org/10.1021/acs.est.2c01094

Houssaine Moutiy, E., Tran, L.H., Mueller, K.K., Coudert, L., Blais, J.F., 2020. Optimized indium solubilization from LCD panels using H2SO4 leaching. Waste Management 114, 53–61. https://doi.org/10.1016/j.wasman.2020.07.002

Pereira, E.B., Suliman, A.L., Tanabe, E.H., Bertuol, D.A., 2018. Recovery of indium from liquid crystal displays of discarded mobile phones using solvent extraction. Miner Eng 119, 67–72. https://doi.org/10.1016/j.mineng.2018.01.022

Yoshida, H., Izhar, S., Mishio, E., Utsumi, Y., Kakimori, N., Feridoun, S., 2018. Application of sub-critical water recovery of tin and Glass substrates from LCD panel e-waste. Detritus - Multidisciplinary Journal for Waste Resources and Residues 04, 98–103.

Zhang, L., Wu, B., Chen, Y., Xu, Z., 2017. Treatment of liquid crystals and recycling indium for stripping product gained by mechanical stripping process from waste liquid crystal display panels. J Clean Prod 162, 1472–1481. https://doi.org/10.1016/j.jclepro.2017.06.159

Zhao, K., Liu, Z., Wang, Y., Jiang, H., 2013. Study on recycling process for EOL liquid crystal display panel. International Journal of Precision Engineering and Manufacturing 14, 1043–1047. https://doi.org/10.1007/s12541-013-0140-9

Acknowledgements:
This work is financially supported by national funds through the FCT/MCTES (PIDDAC), under the project PTDC/CTA-AMB/3489/2021 - RECY-SMARTE - Sustainable approaches for recycling discarded mobile phones, with DOI 10.54499/PTDC/CTA-AMB/3489/2021 (https://doi.org/10.54499/PTDC/CTA-AMB/3489/2021) and UIDB/50006/2020 (DOI 10.54499/UIDB/50006/2020) of the Associated Laboratory for Green Chemistry-Clean Technologies and Processes, REQUIMTE/LAQV, and UIDB/00511/ 2020 (DOI: 10.54499/UIDB/00511/2020) of the Laboratory for Process Engineering, Environment, Biotechnology and Energy (LEPABE) and ALiCE, LA/P/0045/2020 (DOI: 10.54499/LA/P/0045/2020). M. A. D. Silva thanks FCT for the scholarship (ref. 2022.09693.BD).