Comparison of Organic Solvents for Chemical Recycling of Photovoltaic Panels

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The average lifetime of a photovoltaic panel is 20 to 25 years and given the increasing number of solar panels installed each year, the amount of waste photovoltaics is expected to reach 6 million tonnes by 2050 (Dias et al, 2018). This poses a significant problem if processes are not put in place to reuse and recycle solar panel components as many of the materials can be detrimental to the environment if they are put into landfill. Current recycling process tend to focus on recycling only a small number of materials from the module or downcycling the components rather than recycling them. There are three main categories for photovoltaic recycling processes – thermal, chemical, and mechanical (Lunardi et al, 2017). Chemical recycling processes generally involve dissolution by organic solvents to remove the EVA encapsulant before extracting valuable materials from the cell generally via chemical etching (Chowdhury et al, 2020). Chemical etching can be used to the extraction of both silver and silicon from the cell with a high purity however this process can be time consuming, with several hours of etching required to extract most of the material (Kuczynska-Lazewska et al, 2010)

Aim and Approach

This work was designed to explore the effectiveness of different solvents in extracting valuable materials from the photovoltaic cell as well as examining the effect of organic solvents of the EVA structure.
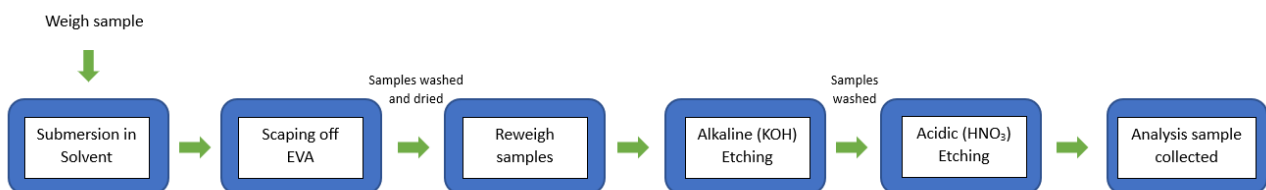

Figure 1: Flow Chart of Delamination and Chemical Etching Process

The initial stage of the experiment involved examining 2 different types of samples (EVA intact and hot knife treated) across 4 separate organic solvents (pentane, hexane, toluene and d-limonene) to determine which were the most effective in extracting silver from the cells. Each cell was submerged in the solvent for 2 hours before undergoing alkaline etching in potassium hydroxide for 15 minutes followed by acidic etching in nitric acid for 3 hours. 10mL of the nitric acid solution was taken for ICP-OES (inductively coupled plasma optical emission spectroscopy) analysis to determine copper, silver, aluminium, and lead content. More in depth analysis was then performed to examine how submersion time effects the removal of valuable metals from the cell. Cell samples

were submerged in d-limonene for 15 minutes, 30 minutes, 1 hour and 1.5 hours respectively before undergoing alkaline and acidic etching. This process was repeated, and an average formed.

Given the difficulty experience in removing the EVA encapsulant from the cells that had not been hot knife treated, a more detailed look at the effect of the solvents on the EVA was performed. Solar cell samples from 3 different photovoltaic modules were submerged in hexane, toluene and d-limonene for 2 hours. Following submersion, the EVA jelly created by the dissolution was removed from the cell, dried and then examined using DSC (differential scanning calorimetry) to determine any change in the EVA structure as a result of the dissolution process.

Results and Conclusions

From the first chemical recycling experiments 4 different solvents along with a control were analysed for the two separate sample types displayed in Figure 2 and 3.
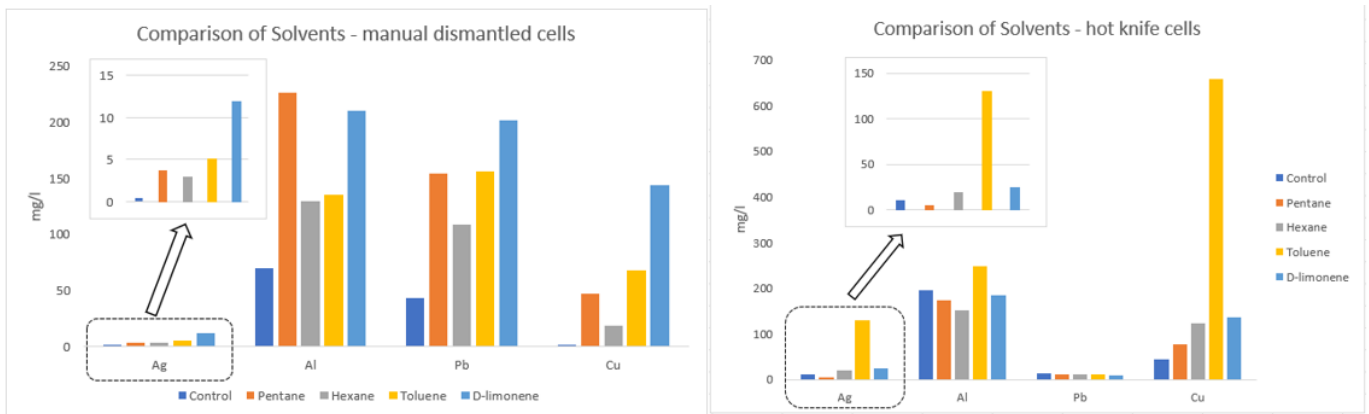

Figure 2: Comparison of solvents for main solar cell elements for EVA intact cells and hot knife cells

For the EVA intact cells, the most effective solvent was d-limonene, with this delamination resulting in the highest levels of silver, lead and copper as well as a high level of aluminium. For the hot knife cells, toluene was the most effective solvent with the highest levels of silver, aluminium and copper followed by d-limonene and hexane. Compared to similar experiments in the literature we would expect approximately 500mg/kg of silver to be extracted from the cell (Kuczynska-Lazewska). This would mean that the delamination process explored here is capable of removing 25% of the silver present in the cells. Between the two cell types, there was no significant difference in the amount of copper and silver extracted between the manually dismantled and the hot knife cells for d-limonene. However, there was a significant increase in the amount of silver and copper extracted by both hexane and toluene using the hot knife samples compared to the EVA intact cells. As a result d-limonene was examined more closely as it was capable of extracting high levels of valuable materials. Toluene was discarded from the remaining experiments as the solvent severely damaged the cell pieces which made the following etching process more difficult.

The submersion time for cells in d-limonene was examined to determine the impact on valuable material extraction. The average of the 3 trials was found and compared for each submersion timing (Figure 4).
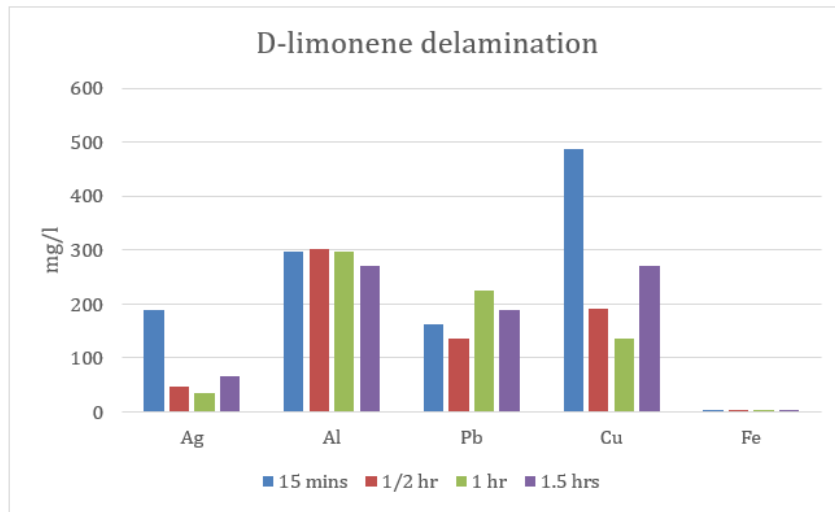
Figure 4: D-limonene submersion time comparison for major cell elements

There was no significant trend between the level of materials extracted and the delamination time using d-limonene. While the 15-minute delamination time had on average a much higher amount of copper and silver present in the samples, statistical analysis shows there is no significant difference in the amount of copper and silver extracted compared to extraction time with p-values of 0.069 and 0.086 respectively. The amount of silver extracted after the 15-minute delamination time represents about 1/3 of the expected total silver content of the cells.

Following this the average amount of each material extracted was compared to submersion time showing that both copper and silver reached peaks in the amount of material extracted at the same submersion time. Lead and iron also had the same trend of peak extraction however this occurred after a longer submersion time compared to copper and silver (Figure 5)
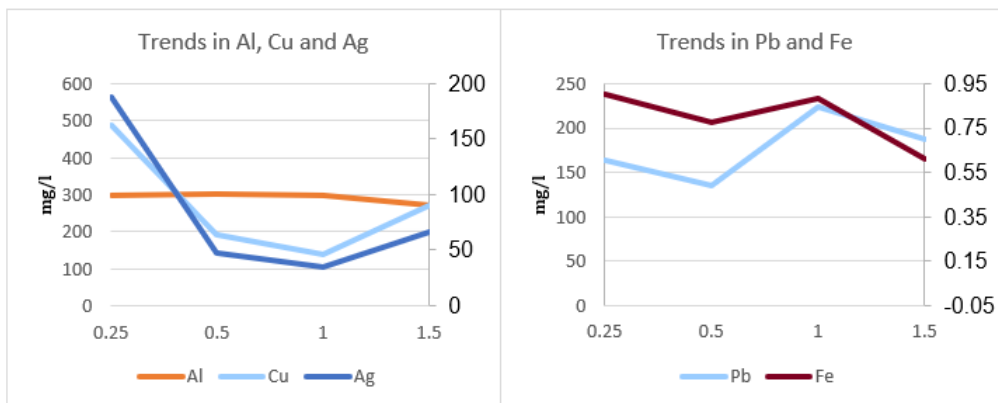

Figure 5: Amount of elements extracted vs time for d-limonene

The effect the organic solvents had on the EVA itself was also examined with the manually dismantled cells being examined using DSC measurements. 3 panels were used for the measurements and the results compared (Figure 6).
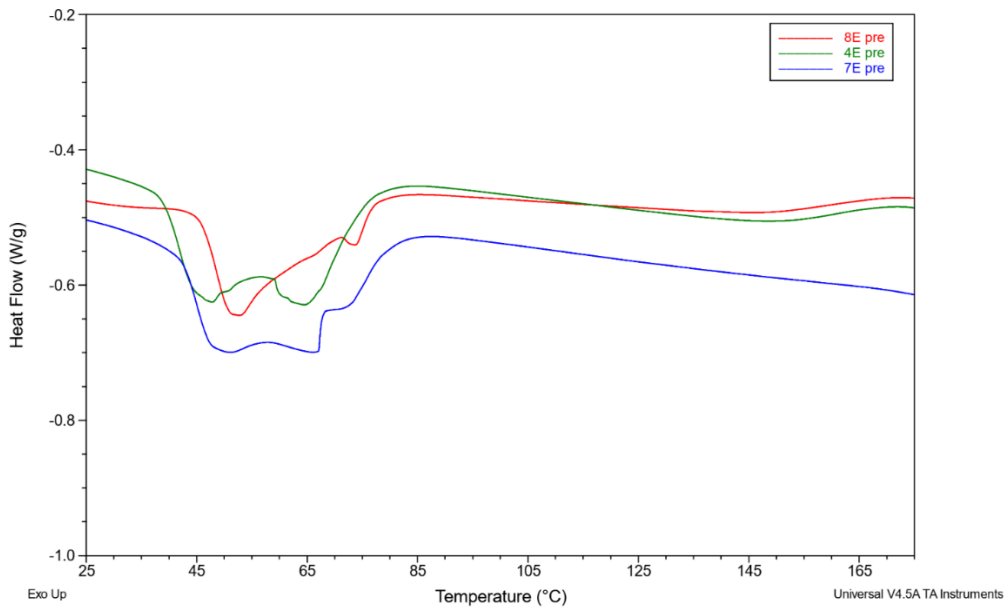
Figure 6: Results of DSC measurements prior to treatment with organic solvents. (4, 7, 8 represent different solar cells from different manufacturers)

Following this 2 of the samples were measured following their treatment in 3 different solvents, hexane, toluene, and d-limonene. These results were then compared with the results prior to treatment with the solvent and are summarised in Figure 7.
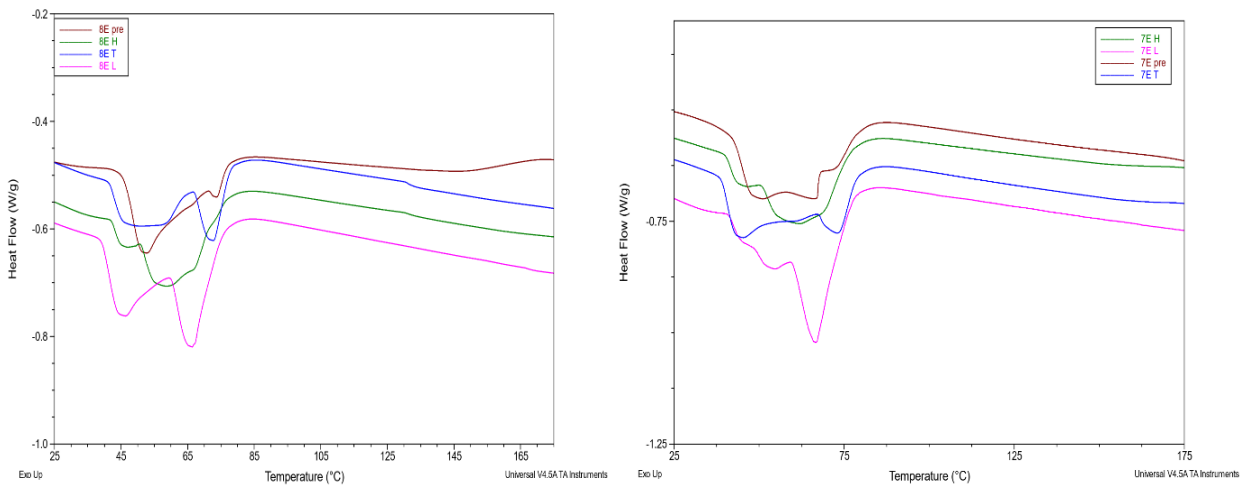

Figure 7: Comparison of DSC measurements following delamination with different solvents between cell 7 (right) and cell 8 (left)

References

Chowdhury, M., K.R., Chowdhury, T., Nuthammachot, N., Techato, K., Akhtaruzzaman, M., Tiong, S., Sopian, K., Amin, N. *An overview of solar photovoltaic panels end-of-life material recycling* Energy Strategy Reviews, 2020. **27**.

Dias, P., L.S., Gomes, L., Bettanin, A., Veit, H., Bernades, A. *Recycling Waste Crystalline Silicon Photovoltaic Modules by Electrostatic Separation* Journal of Sustainable Metallurgy, 2018. **4**: p. 176-186.

Kuczynska-Lazewska, A, Radziemska, E., Sobczak, Z. and Klimczuk, T. *Recover of Silver Metallisation from damaged silicon cells.* Solar Energy Materials & Solar Cells, 2018. **176**: p. 190-195.

Lunardi, M., J.A.-G., Bilbao, J., Corkish, R. *A Review of recycling processes for photovoltaic modules*, in *Solar Panels and Photovoltaic Materials*, B. Zaidi, Editor. 2017, Intech Open. p. 9-28.