Recycling waste solar modules using organic solvents

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ABSTRACT

Photovoltaic (PV) modules contain both valuable and hazardous materials, which makes their recycling meaningful economically and environmentally. The recycling of the waste of PV modules is being studied and implemented in several countries. Current available recycling technology employ the use of high-temperature processes or hydrometallurgical processes, or a combination of both. Recent studies present the use of organic solvents as a mean to separate the PV macro components, and ease PV recycling. This study evaluates the effectiveness and efficiency of an organic solvent (toluene) to promote PV recycling. The separation process includes a combination of manual separation and organic solvent separation. The results obtained show the process employed was able to successfully separate the macro PV components into back sheet, frame, superstrate (glass), Cell/encapsulant/filaments and junction box. The main materials of interest (silver, copper, silicon) were concentrated in a macro component that has only a small fraction (6.37% ±0.005) of the original mass. The process employed approximately 99 hours of immersion and 8.5 hours of active manual manipulation per module. The results indicate that toluene assists in the separation of silicon PV module's components, the process is effective, but efficiency needs to be optimized as the process rendered a loss of 275 grams of toluene per module.

KEYWORDS

Organic solvent; PV recycling; Silicon PV module; Solar module recycling; Toluene; WEEE

INTRODUCTION

Photovoltaic (PV) modules, also known as solar panels, contain both valuable and hazardous materials, which means its end-of-life management and recycling is important from both economic and environmental points of view [1–3]. The current available waste PV recycling procedures include either the use of high temperature processes, the use of leaching agents or a combination of both. Few studies relate the use of organic solvents in the process to enhance material separation and recovery. This study explores the use of toluene as an organic solvent capable of assisting in the recycling process of PV modules and relates the amount of solvent needed to the end separation obtained.

Most solar modules in use globally today are crystalline silicon modules. In 2013, about 85% of the solar panels manufactured were based on crystalline silicon technologies [4]. These modules are composed of several layers with different materials (Figure 1). The first layer is usually made of glass, the second is an encapsulating material usually made of EVA [3]. The silicon cell (monocrystalline or polycrystalline) is the semiconductor, the component responsible for the photovoltaic effect, which is layered along with metallic filaments (silver, copper and aluminum); The silicon cell is placed together with the electrical contacts between two layers of encapsulating material [5]. The rear of the module (also known as substrate) can have different compositions, a combination of polyvinyl fluoride (commercially known as Tedlar) and other polymers being typically used [6]. Previous studies attempted to use organic solvents to separate the encapsulating layer from the remainder using different combinations of solvents, time and temperature [7, 8]. They mainly found that the majority of the tested solvents do not affect the EVA, the exceptions being toluene, tetrahydrofuran, and o-dichlorobenzene [9]. The immersion in appropriate solvent will have two simultaneous effects: the dissolution of the non-cross-linked fraction and the swelling of the cross-linked fraction [7, 9].

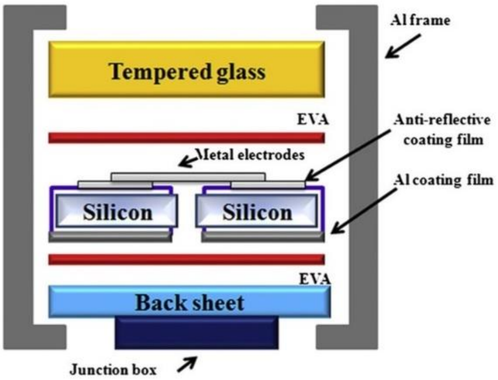

Figure 1: Typical layers of a crystalline solar module [7]

METHODOLOGY

For this study, three commercial crystalline silicon modules were immersed in toluene under controlled conditions to evaluate the effect of the immersion, time of the process, material usage and quality of the outcome (separation effectiveness). The modules were identical in electrical properties (maximum power, maximum power voltage, maximum power current, etc.), dimensions (220 mm x 250 mm x 18 mm) and cells per module (36 polycrystalline silicon). The modules were weighed, and their weight was also identical equalling 654g. Before immersion, all modules underwent a manual separation of the aluminium frame and the junction box (Figure 1). The modules were then placed in an aluminium container (500 mm x 350 mm), to which 1.3 kg of toluene (99.5%, analytical grade) was added. The container was then sealed with a glass lid, a rubber band on the interface glass-aluminium and binder clips throughout the sides. Moreover, the glass lid had an escape valve to which a reflux system was coupled, as shown in Figure 2. The whole system was placed on a heating plate controlled by a thermocouple, and was kept at 90 ºC, which, according to previous studies, reduces the immersion time needed to separate the EVA [7]. The modules remained immersed for 99 hours, regular toluene top ups were necessary every 20 hours to maintain the module fully immersed. After 99 hours, the modules were removed from the container. Manually, the macro components were separated and weighed.

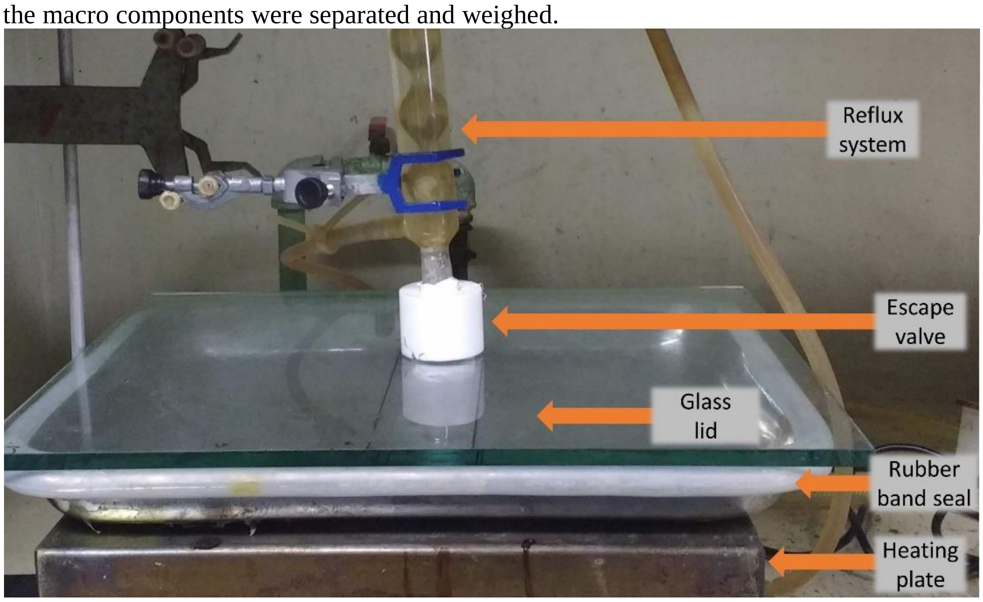

Figure 2: System used to immerse the silicon PV modules in the toluene solvent

RESULTS

After 99 hours immersed in toluene, several of the components were easily separated manually. The total toluene lost in the process (due to vaporization and vapor escape) equalled approximately 275 g per module. The glass was separated whole, without any cracks. Most of the silicon cells were separated from the glass layer (they are attached to each other by the encapsulating EVA), however, some remained attached and had to be manually scraped with a spatula to fully removed the cells. The separation process yielded 97% of the original mass (i.e., 3% mass loss during the process), mostly due to dissolving and swelling EVA parts which were not recovered from the solution. The end result had the following macro components: Back sheet, frame, superstrate (glass), Cell/encapsulant /filaments, junction box (Figure 3). The mean manual labor time used in the process was 8 hours and 30 minutes per module, which includes the manual separation, the system setup and the regular toluene top ups.

Figure 3: Macro components separated using organic solvent. Starting on the top left of the image and going clockwise: back sheet, frame, junction box (inside the frame), substrate, loose cell/encapsulant/filaments, scraped cell/encapsulant/filaments, property labels

CONCLUSION

The results show that toluene is capable of separating the macro components of waste PV modules. The shortfalls of the process are the amount of toluene lost during the process (275 grams per module) and the amount of manual labor that needs to be employed (approximately 8.5 hours per module). Nevertheless, this process is capable of facilitating the recycling of waste PV and the recovery of important resources because it is capable of effectively separating components that typically increase the difficulty in the separation of waste PV modules [7, 9]. Further recycling processes can be employed to further recover other materials. Moreover, the main materials of interest (silicon, copper and silver) were all concentrated in a small fraction (6.37% ±0.005) of the original mass (654g). Under the conditions tested, an initial manual separation followed by a 99 hours toluene immersion at 90 ºC can separate the waste PV into back sheet, frame, superstrate (glass), Cell/encapsulant/filaments, junction box. Future studies can optimize the process to reduce the toluene loss, the time needed and the amount of manual labor required to obtain this separation.

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