Enabling an Ecosystem for Recycling Waste Polarizers

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Abstract

This paper demonstrates the complete waste polarizer recycling and upcycling ecosystem designed by ITRI. Thousands of tons of discarded polarizers have been transformed into usable and valuable potential products, rather than being landfilled or poisoning the planet.

In this paper, ITRI's green recycling ecosystem for waste polarizer processing will be introduced. Over the years, ITRI has developed a series of green and efficient technologies, including a unique aqueous deiodination agent, and precise polymer mixture separation technologies for r-PVA. Additionally, several very promising upcycling applications of r-PVA and r-TAC were proposed.

Author Keywords

Polarizer, Green Technology, Recycling, Sustainable

1. Introduction

Polarizer is one of the main components in LCD displays that filters light waves. Polarizers usually have a 5-7-layer structure, including a main polarizing layer, upper and lower adhesive layers, upper and lower protective/release layers, and optical compensation film. The polarizing layer is made of stretched polyvinyl alcohol (PVA) iodine-dyed film[1], TAC, PET, COP and other polymers, as shown in **Figure 1**. The composition and structure of polarizer itself are complex and are generally considered difficult to recycle.

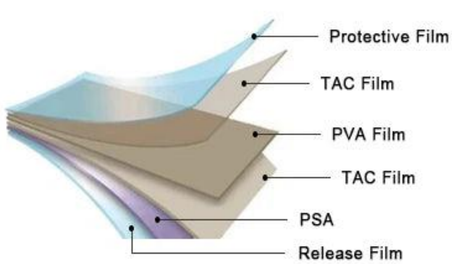

Figure 1. Basic Structure of Polarizers[2]

Taiwan has been a major center for the LCD industry for decades. Not surprisingly, discarded polarizers are reported to increase by tens of thousands of tons every year, some from the manufacturing process and some from discarded LCD displays. In order to avoid purple smoke produced by iodine sublimation during the incineration process, discarded polarizers are usually landfilled, which has a great impact on the environment. In addition, these optical grade polymers in polarizers cannot be recycled and reused. Therefore, an emerging approach is needed[3][4][5][6][7].

2. ITRI's strategy of resource recovery for waste polarizers

In order to achieve the goal of net-zero emissions in 2050, ITRI has formulated a "resource recycling and zero waste" strategy for discarded polarizers, hoping to maximize resource recycling and minimize waste disposal.

Figure 2 shows the overall resource circulation plan developed by ITRI for discarded polarizers. We hope to use our innovative technology to convert waste polarizers into value-added upcycling applications and even those that cannot be processed at the end can be used as SRF (solid recovered fuel) materials to improve the incineration efficiency and achieve the ultimate goal of zero waste.

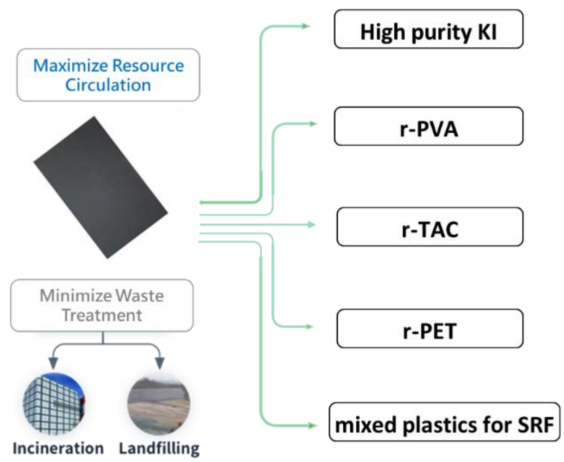

Figure 2. Overall Resource Circulation for Waste Polarizers

3. Waste polarizer green recycle process demonstration line

In order to achieve economies of scale and quickly connect large-scale production, ITRI built a ton-scale waste polarizer deiodination demonstration line last year. The maximum processing capacity of each batch could reach 80~100Kg of pre-crushed waste polarizer. A unique water-based deiodination agent formula is adopted to meet the needs of low volatile organic compound (VOC) and health concerns. The actual processing time only requires stirring at a certain temperature for 1~2 hour to achieve good deiodination effect. It is not difficult to find the original black fragments have turned into a white solid appearance. The following process collects different forms of polymers through simple separation equipment. One group is water-soluble, mainly PVA in liquid form, and the other group is water-insoluble, which is a mixture of PET, TAC and other polymers in solid form. It is estimated that more than 94% polymers can be collected. Besides, considering overall green ecosystem, ITRI also conducted wastewater reduction research and found that the water

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extractant can be collected directly after the deiodination treatment and can be reused multiple times through simple adjustments.

Figure 3. ITRI's ton-scale waste polarizer deiodination demonstration line

4. Deiodination Study

Deiodination efficiency

The deiodination efficiency can be measured by using a UV-Vis spectrometer to measure the characteristic absorption peak of iodine ion(I^-)(λ=225nm)[8]. As shown in **Figure 4**, the iodine removal rate is greater than 99%, which is also double confirmed by ICP-MS.

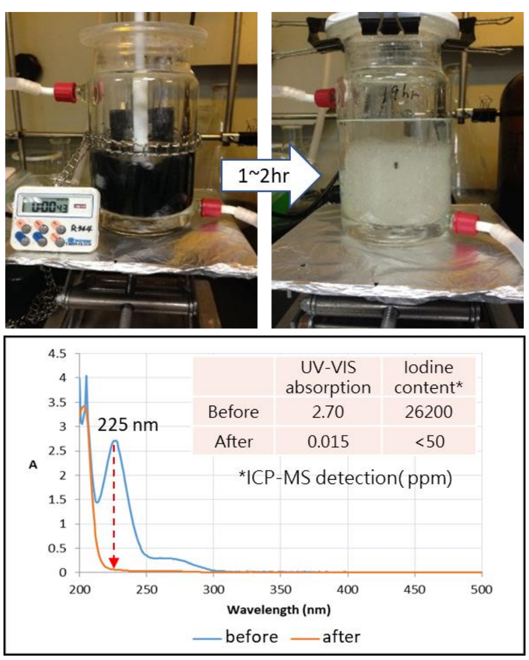

Figure 4. The measurement results of iodine-dyed PVA single film before and after deiodination treatment.

Water extractant reuse test

In order to reduce the amount of waste water, the reuse of water extractants was studied. It was found that adjusting the pH value of the extractant can refresh the extractant. Even if the extraction agent is reused for the fifth time, the deiodination efficiency of a 5-layer waste polarizer is similar, as shown in Figure 5.

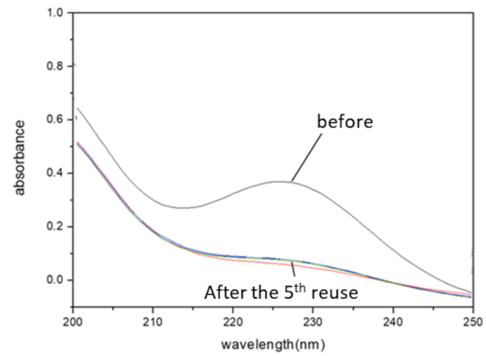

Figure 5. The refreshed extractant reuse test.

Solid recovered fuel (SRF) application

The use of SRF to offset the energy demand of fossil fuels and reduce carbon emissions has received increasing attention in recent years[9]. According to ISO 21644:2021, the relationship between SRF LHV (lower heating value) and boiler power efficiency is as shown in Table 1.

According to the SGS report, the LHV measurement results of the polymer mixture compositions of the two deiodinated waste polarizers are both greater than 5000 kcal/kg, as shown in Table 2. For cement kilns and coal-fired power plants with high energy consumption and high combustion efficiency, deiodinated waste polarizers is considered as a potential solid fuel to reduce the use of electric heat.

Table 1. Relationship between SRF LHV and boiler power efficiency

SRF LHV (lower heating value)	boiler power generation efficiency
>5,000 kcal/kg	>25%
>4,500 kcal/kg	20~25%
>4,000 kcal/kg	<20%

Table 2. LHV data of recycled polymers (by SGS)

	deiodinated waste polarizers	r-PVA
LHV (lower heating value)	**5,520 kcal/kg**	**7,207 kcal/kg**

5. Promising upcycling applications

It is indeed for most people who want to get into recycling industries, financial incentives are most crucial. High costs and low returns discourage circularity incentives. Therefore, enabling high-value applications is always a top priority.

The following are some value-added application suggestion for waste polarizer recycling polymers.

r-PVA

R-PVA are currently most successful recycled polymer in our system. As mentioned above, r-PVA polymer, unlike other polymers in polarizers, can be capatured by our water-base extractant and therefore appears to be water-soluble. But strictly speaking, the structure of PVA in polarizer is not like a traditional linear polymer. It is cross-linked through deeply chelated boric acid, much like network structure. So, it is actually in swollen with a lot of water. In our study, r-PVA can be converted into a water-repellent agent through some functional modifications, As shown in Figure 6, some fabrics using our modified r-PVA coating exhibit excellent waterproof properties. It is expected to become a substitute for PFAS and can be widely used in packaging, construction, papermaking and other fields.

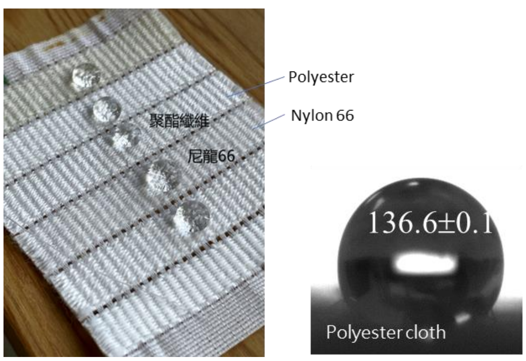

Figure 6. The water-repellent properties of modified r-PVA.

In recent years, with the development of e-commerce, the demand for cold chain logistics applications has continued to increase. Figure 7 shows the cooling maintenance time of our r-PVA coolant compared to commercial coolants, comparing the time spent to return to 5 degree Celsius after removal from the freezer. Cooling is maintained approximately 3 times longer (approximately 55 minutes) than commercial coolants (18 minutes).

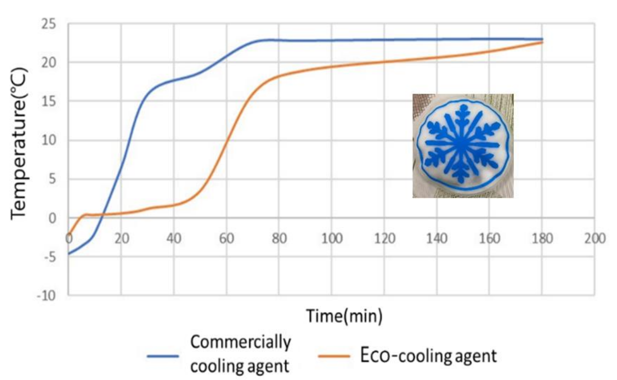

Figure 7. The cooling maintenance time of our r-PVA coolant compared to commercial coolants.

r-TAC

It is understood that the weight proportion of triacetyl cellulose (TAC) in polarizers is greater than 50%, and TAC recycling is undoubtedly more important in polarizer recycling. However, the market application demand of TAC is lower than that of di-acetate cellulose (DAC). In addition, the depolymerization/degradation process of TAC is also uneconomical錯誤! 找不到參照來源。. In view of the excellent optical properties of TAC, ITRI is cooperating with some local companies to upgrade r-TAC for applications such as sunlight filter films or packaging bags for high-end electronic products. As of now, some technical issues remain, such as suitable colorant and improvement in moisture barriers.

6. Conclusion

To achieve the goal of net-zero emissions in 2050, ITRI has established a complete resource recycling ecosystem to convert discarded polarizers into value-added upcycling applications. Through the ton-level demonstration line, the high-efficiency, low-wastewater deiodination process was demonstrated. High LHV recycling polymers such as SRF have been demonstrated. In addition, some potential upcycling applications are also proposed. We believe that ITRI can not only provide a sustainable recycling ecosystem for the recycling industry, but also create new opportunities for a better green future for Taiwan's LCD industry.

7. Acknowledgement

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