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Exploring Alternative Energy Sources for Antarctic Stations: Integration of Solar Panels into Building Infrastructure

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Abstract

The dye present in dye-sensitized solar cells (DSSC) is responsible for converting sunlight into an electron flow. These pigments can be extracted from natural sources, providing a means to utilize typically lost or discarded resources, such as algae deposited on the coast or unmarketable fruits. By using anthocyanins extracted from the flower of the ceibo tree (Erythrina crista-galli), two small panels were assembled and installed at the Artigas Antarctic Scientific Base, allowing for remote evaluation of their performance over a period of 19 months. Located inside a room behind a window, the panels demonstrated excellent stability during the evaluation period. They were also able to generate electrical energy from artificial light sources near the installation area and had the capacity to produce electricity during the low-radiation winter months, where snow could potentially play a significant role by functioning as a large mirror. This research describes an interesting advancement in expanding the energy matrix of the Antarctic bases by utilizing typically discarded natural resources to potentially play a relevant role.

Keywords

Anthocyanins, Photovoltaics, Renewable energy

Introduction

Solar cells based on the use of pigments (known as DSSC, an acronym for Dye-Sensitized Solar Cells or Graetzel cells) were first reported in the 1990s (O'Regan et al., 1991). Since their discovery, they have garnered significant interest, as evidenced by numerous reports in the literature and their application in various fields, including personal devices, greenhouses, and building integration (Bandara et al., 2022; Pirrone et al., 2022; Fagiolari et al., 2022; Barichello et al., 2021; Muñoz et al., 2021). Their energy conversion efficiency has continuously improved, reaching values of up to 34% under ambient radiation conditions of 1000 lux (Zhang et al., 2021). However, the use of natural pigments, although less efficient than synthetic ones, remains appealing given their low cost and widespread availability. Additionally, they offer an alternative application for resources that are discarded or go to waste, such as algae deposited on coastal or river shores and unmarketable fruits.

In a DSSC, the pigment deposited on the photoanode plays a crucial role in capturing sunlight and converting it into an electron flow. In our laboratory, we have evaluated numerous compounds found in nature for their use in DSSCs, many of which were obtained from algae and bacteria collected on King George Island (Cerdá, 2022; De Bon et al., 2022; Gonzalez et al., 2022; Marizcurrena et al., 2021; Cerdá et al., 2020; Yañuk et al., 2020; Montagni et al., 2018; Enciso et al., 2017). Among these, anthocyanins derived from the ceibo flower have allowed us to assemble the most efficient cells yet. These cells have been selected for the construction of the panels installed at the BCAA.

DSSCs possess a crucial characteristic that sets them apart from traditional silicon-based cells: their translucency, enabling the passage of light through them. This feature allows for their installation in windows, meaning they are integrated into the building structure.

Figure 1. *DSSC panels on the windows of the Swiss Convention Center, located in the city of Lausanne.*

The installation of this technology in Antarctic stations deserves consideration. These panels could contribute to diversification of the energy matrix by better harnessing solar light, particularly during the winter months when traditional silicon panels either shut down or significantly reduce production (sometimes due to snow coverage). An outdoor photovoltaic panel in a region like Antarctica will inevitably be covered by snowfall, preventing sunlight from reaching it. However, this is not the case with DSSC panels since they are installed within buildings, providing energy to the enclosed space, and protecting it from harsh weather conditions. Additionally, these panels can be assembled using pigments obtained from the surrounding environment. Moreover, if natural pigments are used, low temperatures at the location help preserve the colorants (Szadkowski et al., 2022; Ahn et al., 2014).

Results and Discussion

In our laboratory, we have explored various natural-origin pigments/dyes which can be grouped according to their structural characteristics, such as proteins, carotenoids, xanthophylls, indoles, and anthocyanins. We have observed a significant correlation between the size of the evaluated molecule and cell efficiency, as electrode surface coverage is crucial.

Our best results reached an efficiency of 0.7% using anthocyanins from the ceibo flower. For this reason, individual cells were first assembled using the ethanol-extracted anthocyanins, purified, and then applied to the photoanode. Finally, the cells were sealed and individually evaluated; the most efficient were selected for panel assembly.

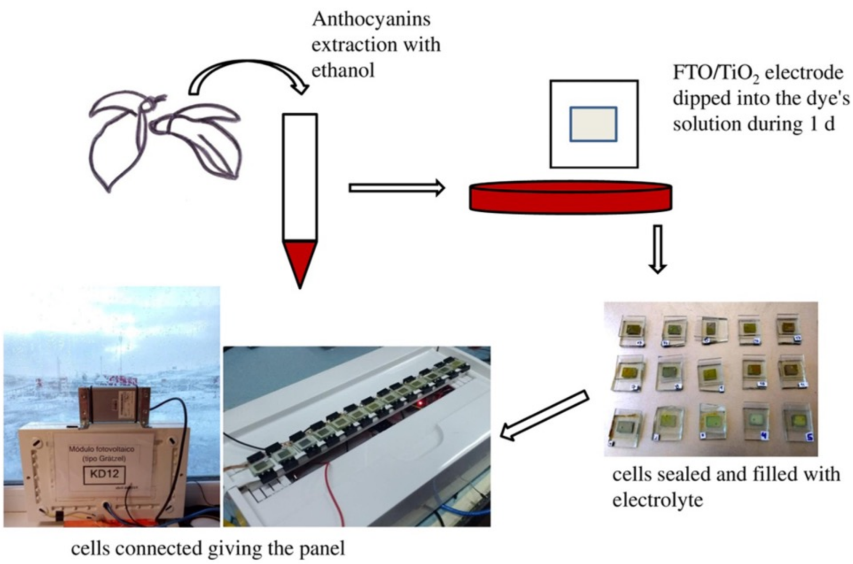

Figure 2. *Assembly schematic of one of the panels (taken from Cerdá, 2022).*

The primary objective of this study was to assess the feasibility of utilizing these devices in Antarctica and analyze their stability and operational characteristics. Therefore, opaque materials were used for panel construction as they incurred a lower cost. While the technology's main appeal lies in its ability to allow the passage of light, the required materials (as shown in Figure 3) are much more expensive.

Figure 3. *Translucent individual cell, from which panels with similar characteristics can be constructed.*

The panels were installed near a window at the Artigas Antarctic Scientific Base (parallel to it and oriented NW) and connected to an ARDUINO device that allowed remote monitoring of their generated power values over time. One panel (named KD12, panel area 9 cm2) was fully monitored, yielding voltage and current intensity data. In the case of current intensity, voltage data were measured on one of the ARDUINO board channels from a circuit containing an external resistance of 5.5 k ohms. The collected data were compared with those from a reference monocrystalline silicon solar sensor (area 15 cm2) connected to the same ARDUINO board as the KD12 panel. Through this, and by considering the irradiance values measured over time, the performance of the DSSC panel could be compared to that of the silicon sensor over the same period.

The trend in radiation received by the equipment was in line with expectations: it is minimal in the winter months (June/July) and highest in the summer months (December/January). A similar occurrence was found with the silicon sensor's data generation, where the peaks occurred during periods of maximum radiation. However, the power generated by the DSSC panel did not follow the same trend. As shown in Figure 4, the power generated by the DSSC panel (KD12) was independent of the incident radiation

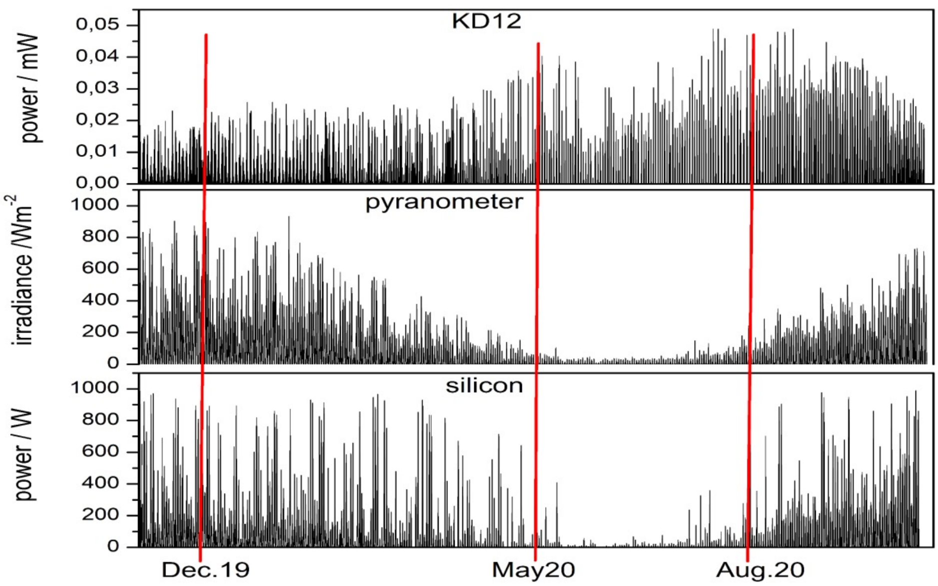

Figure 4. *Data of power generated by the DSSC panel (KD12), along with radiation data measured by a pyranometer and generated by silicon panels during the 19 months of monitoring (taken from Cerdá, 2022).*

Upon examination of the data presented in Table 1, in June/2019 and December/January of that year, the generated power behaves as expected in clear accordance with the received radiation. However, this does not occur in the following winter, where during the months of June and July/2020, precisely the opposite happened: the panel maintained its generation capacity, to the extent where its energy conversion efficiency (PCE) was among the highest measured values.

Month	Average power mW	Maximum voltage V,	PCE %
June19	0.0021	0.19	0,0054
Dec. 19	0.024	0.49	0,0031
January 20	0.024	0.47	0,0032
June 20	0.031	0.48	0,0774
July 20	0.045	0.52	0,0462

Table 1. *Average powers calculated from the data generated by the KD12 panel, alongside data of maximum average voltage (taken from Cerdá, 2022).*

To assess this observation, it was necessary to consider the influence of other factors, such as the presence of snow or artificial light near the window where the panel was installed. These hypotheses were reinforced by measurements taken in our laboratory in the city of Montevideo. On one hand, the device showed an interesting power generation capacity when illuminated with artificial light. On the other hand, its performance was measured during the winter in our city, where the average temperature is 10°C but where snowfall is never recorded. Under these conditions, with low radiation (natural light) of 60 W/m2, the KD12 panel was able to generate 0.005 mW of power with a maximum measured voltage of 0.20 V. Further research is necessary to confirm the hypothesis.

The comparison of the DSSC panel's behavior with that of monocrystalline silicon is also interesting. Firstly, in contrast to the reaction with DSSC, the silicon sensor showed no response when illuminated with artificial light. The artificial light from the light fixtures has a lower intensity than sunlight, especially when originating from external fixtures located near the window where both panels were installed. Furthermore, the spectrum (i.e., the range of energies involved) significantly differs to that of natural light.

The small silicon panel was only able to generate voltage when irradiance values exceeded 100 W/m2. This difference in sensitivity could have interesting practical consequences.

Conclusions

The DSSC panel constructed using ceibo flower extracts was able to generate power and voltage values throughout the evaluation period while maintaining conversion efficiency levels. This operational stability is crucial when considering the potential application of this technology to diversify the energy matrix in Antarctic bases.

This type of panel demonstrated an apparent capability in utilizing artificial lighting sources located in its proximity. Additionally, there were indications that it could harness light reflected by the snow, resulting in a higher power generation than expected, based solely on the irradiance measured by an external pyranometer.

Lastly, it is estimated that the panel's location in a low-temperature zone and behind a glass surface may have contributed to stability maintenance of the pigments used. Since these pigments are of a natural origin, exposure to high temperatures and UV radiation (filtered in this case by the window glass) can lead to their degradation.

The observed results warrant further investigation into the potential of DSSC panels as energy harvesters in extreme conditions, such as the Antarctic environment.

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