Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Evaluation of the potential of organic dyes for the production of nanocrystalline solar cells

Renan Angrizani de Oliveira
Professor PhD, UNISO, Brazil.
renan.oliveira@prof.uniso.br

Juliana Heloisa Pinê Américo-Pinheiro
Professor PhD, UNESP, UB, Brazil.
juliana.heloisa@unesp.br
juliana.pinheiro@ub.edu.br

Arthur Pereira dos Santos
PhD student, UNESP, Brazil.
arthur.p.santos@unesp.br

Darllan Collins da Cunha e Silva
Professor PhD, UNESP, Brazil.
darllan.collins@unesp.br

Diego Aparecido Carvalho Albuquerque
Professor PhD, UNISO, Brazil.
diego.albuquerque@prof.uniso.br

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

ABSTRACT

With the increase in global energy demand and the necessity to reduce greenhouse gas emissions, the need to generate energy from clean and renewable sources is undeniable. In this context, solar energy stands out as a promising energy source because it is inexhaustible and has reduced environmental impacts compared to other energy sources. The present study aimed to fabricate and evaluate the efficiency of a Dye-Sensitized Nanocrystalline Solar Cell (DSSC) through the preliminary assessment of the transmittance of different tea-based dyes using optical spectroscopy. To obtain the dyes, different teas were used: mate, apple with cinnamon, apple with vanilla, lemongrass, fennel, red fruits, and mint in various concentrations. These were then subjected to optical reading at transmittance wavelengths (400 nm to 900 nm). A DSC was produced for efficiency evaluation, which was conducted through Voltage vs. Current and Power vs. Resistance relationships. The results obtained from the transmittance analysis of the dyes showed that the higher the dye concentration, the lower the transmittance. Among the teas evaluated, red fruit tea at the highest concentration achieved the best result. The electrical characterization performed on the cell produced with the red fruit tea dye showed maximum power values of 8 µW for a 700 Ω load resistance. The technique employed for the preliminary transmittance analysis of the dyes yielded satisfactory results in terms of cost reduction and rapid applicability.

KEYWORDS: Solar energy. Organic photovoltaics. Renewable energy.

1 INTRODUCTION

Population growth has been causing an increase in global energy demand, making it necessary to seek new energy sources. However, fossil fuel-based energy sources directly impact the increase in greenhouse gas (GHG) emissions, intensifying the rise in the global average temperature. Therefore, it is undeniable that there is a need to invest in clean and renewable alternative forms of energy production (ALONSO et al., 2012; LAERA, 2013; FEITOSA et al., 2018; AHMED et al., 2023).

Aiming to reduce GHG emissions and meet the growing global energy demand, solar energy is presented as a promising source, given that its source is inexhaustible and the environmental impacts of energy generation are reduced compared to non-renewable energy sources. Furthermore, solar energy stands out as a sustainable energy source with great potential for energy generation, considering that the amount of solar radiation that hits the Earth in one hour is equivalent to the world's annual energy demand, yet it is still underutilized for electricity generation (VARELLA; CAVALIERO; SILVA, 2008; SOLANGI et al., 2011; GONG; LIANG; SUMATHY, 2012; LIMA; SOUZA; LOPES, 2022).

Solar energy can be classified into four categories: photovoltaic energy, solar thermal energy, concentrated photovoltaics, and solar chimney. The most common are photovoltaic systems, which convert the Sun's radiant energy directly into electrical energy. However, one of the negative aspects of using photovoltaic cells is their high cost and low energy conversion efficiency (REIS, 2011; SHARMA, 2022).

A promising solution to the high cost and complex manufacturing process of conventional photovoltaic cells is the Dye-Sensitized Solar Cell (DSSC), proposed by O'Regan and Grätzel (1991). This photovoltaic device uses organic dyes in its production, making it a lower-cost method compared to conventional solar cells, which use silicon as the primary material in their production (AGNALDO et al., 2006; ANDUALEM, DEMISS, 2018).

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

The photovoltaic cell system created using organic dyes by O'Regan and Grätzel (1991) is based on the observation of the photosynthesis phenomenon, a process in which plants generate chemical energy by absorbing sunlight. This led to the development of a cell model that converts solar energy into electricity using organic dyes.

The dye used in DSSCs has the capacity to absorb photons, which, when absorbed, excite and transfer electrons to the conduction band. The generated electron flow then travels to the layer where it is collected as an electric current. Therefore, the dyes are fundamental in energy production and must be able to absorb light across a wide spectral range (GONG; LIANG; SUMATHY, 2012; ANDUALEM, DEMISS, 2018).

The production method of DSSCs has been the subject of study by numerous researchers, who have made progress in its development and application. This can be attributed to the quest for a better understanding and improvement of this new photovoltaic cell model, aiming to enhance its energy efficiency and consequently its competitiveness with conventional silicon cells (PETER, 2011; GONG; LIANG; SUMATHY, 2012; SONAI et al., 2015; SUN et al., 2023).

Given the importance of developing new technologies to meet energy demand and reduce the current cost of photovoltaic cells, this experimental study aimed to investigate the efficiency of DSSCs by initially evaluating the transmittance of the dyes analyzed through optical spectroscopy.

2 MATERIALS AND METHODS

According to the model proposed by Azevedo and Cunha (1991), the production of the DSSC was carried out, and subsequently, the efficiency of the produced cell was analyzed through the Voltage vs. Current and Power vs. Resistance relationships. The choice of the O'Regan and Grätzel method (1991) was motivated by its low cost and simplified manufacturing process compared to conventional photovoltaic cell technology.

2.1 Production of Dyes

To obtain the dyes, different types of tea bags were used, including: mate; apple with cinnamon; apple with vanilla; lemongrass; fennel; red fruits; and mint in different concentrations. For the preparation of all teas, the water was preheated to 90°C and measured with a thermometer.

For concentration (1), 100 ml of water was added to each tea bag for 6 minutes. In the production of the dyes at concentrations (2) and (3), the same preparation criteria as concentration (1) were used, varying the volume of water. In concentration (2), 200 ml of water was used for one tea bag, and for concentration (3), 400 ml of water was used for one tea bag.

2.2 Evaluation of Dyes

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

In order to identify the best dye produced for the fabrication of the DSSC, all organic dyes based on different teas with different concentrations were analyzed. They were subjected to transmittance analysis by optical spectroscopy in the wavelength range from 400nm to 900nm.

For the estimation of the energy generation potential of the produced dyes, characterizations were performed on a spectrophotometer (Ocean Optics - Red Tide USB650 Model) with a glass cuvette.

From the obtained data of dye transmittance, it was possible to estimate the region of the electromagnetic wave spectrum where energy absorption by the dyes occurs. Thus, the obtained spectra allowed for the comparison of dyes based on their concentration and transmittance.

2.3 Production of Dye-Sensitized Nanocrystalline Solar Cell (DSSC)

Identifying the dye and concentration with the highest photon absorption potential, based on the transmittance analyzed for each dye at different concentrations, a DSSC was then produced using the methodology proposed by Azevedo and Cunha (1991), which involves the preparation of two electrodes, one negative and the other positive.

2.3.1 Production of Negative Electrode

The production of the negative electrode was carried out on a glass slide coated with indium tin oxide (ITO), with a resistivity of 70-100 Ω sq-1, measuring 25 mm² by 1.1 mm in thickness (Sigma-Aldrich). The glass slide was cleaned with reverse osmosis water and then dried using a hot air blower at 300°C (Steinel - HL1500 Model).

The semiconductor was prepared by dissolving 3 g of titanium dioxide - TiO2 (Merck) in 6 mL of nitric acid 65% P.A. (Modern Chemestry), forming a pasty solution. This solution was then spread over the conductive surface of the ITO-coated glass using a glass rod, resulting in a uniform film with a thickness of 2 mm.

Posteriormente, a lâmina com o filme de TiO_2 foi levada para secagem em uma chapa aquecedora, previamente aquecida à 300°C por 5 min para a remoção da umidade da lâmina, e posteriormente, para que houvesse o recozimento do filme do TiO_2, levada para secagem em mufla (Quimis – Modelo Q318M) à 550°C por 10 min.

Subsequently, the slide with the TiO2 film was taken for drying on a heating plate, previously heated to 300°C for 5 minutes to remove moisture from the slide. Then, for the annealing of the TiO2 film, it was transferred for drying in a muffle furnace (Quimis - Model Q318M) at 550°C for 10 minutes.

After cooling, the slide was immersed in the organic dye based on tea at a temperature of 20°C for 5 minutes, so that the TiO2 paste acquired coloration.

2.3.2 Production of Positive Electrode

For the production of the positive electrode, a glass slide coated with ITO was used,

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

employing the same cleaning and drying method as the negative electrode.

The catalyst was applied by coating the conductive side of the slide with graphite using a 2B pencil.

2.3.3 Assembly of the Dye-Sensitized Nanocrystalline Solar Cell (DSSC)

After preparing the electrodes, they were joined using two binder clips, with the conductive parts facing the inner part of the junction.

To activate the cell, 0.25 mL of electrolyte was placed on the side of the cell, prepared following the methodology of Freitas (2006), which involved using 0.05 mol of sublimed iodine - I2, crushed with the aid of a spatula, and adding 0.5 mol of potassium iodide - KI, diluted in 30 mL of ethylene glycol - C2H4(OH)2.

2.4 Electrical Characterization of Dye-Sensitized Nanocrystalline Solar Cell (DSSC)

To determine the efficiency of the produced DSSC, voltage (V) and current (I) measurements were conducted to obtain an I-V curve at different resistance (R) values. Consequently, power was obtained depending on the applied resistance.

To obtain the measurements, a 100 W incandescent lamp was used, positioned on a universal tripod 4 cm away from the cell. Cables were connected to the ends of each cell electrode, which were linked to: a circuit with a multimeter (Minipa - Model ET-2042D) for voltage measurement; a resistance decade box (Minipa - Model MDR-610) to vary the resistances; and current measurement was conducted using a digital multimeter (Agilent - Model 34401A).

3 RESULTS AND DISCUSSION

According to Freitas (2006) and Gong, Liang, and Sumathy (2012), the DSSC makes a better use of a wide range of luminosity because organic dyes can absorb radiation in the visible and near-infrared regions. Additionally, they exhibit lower sensitivity to the angle of incidence of the radiation and can operate in a temperature range of up to 70°C.

3.1 Dyes Evaluated in the Study

The analysis of the transmittance of the dyes at different concentrations, conducted in the range of 400 nm to 900 nm, allowed for the verification of the performance of the dyes in generating electrical energy in DSSCs

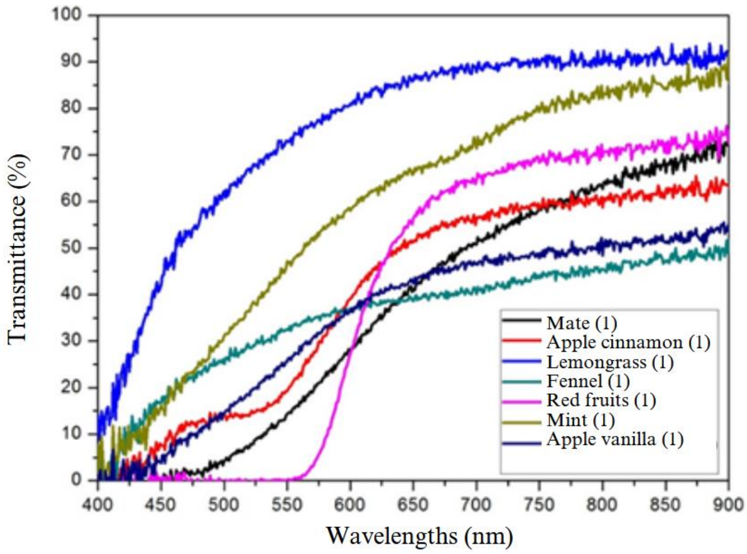
Since titanium dioxide (TiO2), a semiconductor commonly used in DSSCs, absorbs light at wavelengths below 400 nm, it is necessary to use dyes capable of absorbing a wide range of the solar spectrum, such as the visible and near-infrared regions (Murakoshi et al., 1998; Gong, Liang, & Sumathy, 2012).

The transmittance results of the teas showed that, for the highest concentrations (1), there was a significant reduction in transmittance and, consequently, greater absorption.

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

While for concentrations (2) and (3), a higher transmittance was observed in all the analyzed dyes. Thus, for the evaluation of the dyes, only those with the highest concentration were selected, as shown in Figure 1.

Figure 1 - Transmittance graph of the analyzed teas

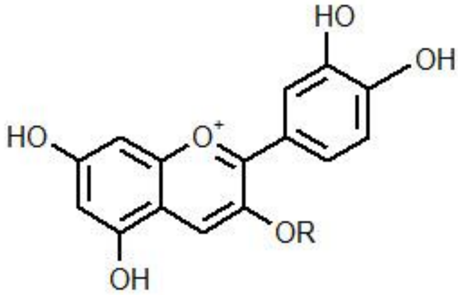


Source: The authors, 2024.

Upon analysis of the results (Figure 1), all dyes at the highest concentration (1) showed the best absorption results. However, the dye obtained from red fruit tea (1), followed by mate tea dye (1), and apple cinnamon tea (1) exhibited the highest potential for energy generation due to the reduction in transmittance across a broader spectrum region.

Therefore, the best light absorption result was presented by the dye produced with red fruit tea, suggestive of the presence of anthocyanin (Figure 2), which consists of a group of water-soluble pigments widely studied and commonly used in the food industry as natural colorants (LOPES et al., 2007). This natural pigment is responsible for the red, blue, and purple colors in flowers and fruits, where color variation is also influenced by the pH (MAEDA-YAMAMOTO et al., 2012; ROY; RHIM, 2020).

Figure 2 - Chemical structure of the anthocyanin present in red fruit tea

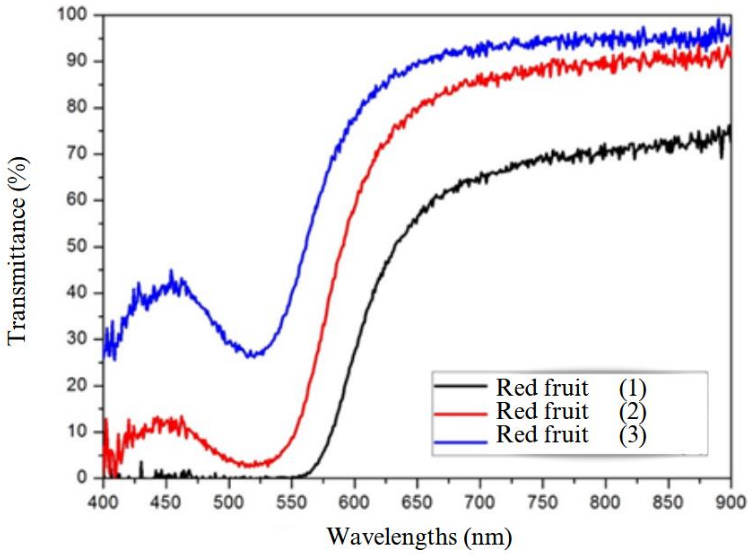


Source: The authors, 2024.

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Thus, it was found that this pigment is responsible for the coloration of red fruit tea (Figure 3), which showed a decrease in transmittance at a wavelength near 530 nm, corresponding to the π-π* electronic transitions arising from the anthocyanins (CALOGERO et al., 2009; PATROCÍNIO; IHA, 2010; MAEDA-YAMAMOTO et al., 2012; SONAI et al., 2015).

Figure 3 - Transmittance graph for the red fruit tea dye at different concentrations



Source: The authors, 2024.

The concentrations (2) and (3) of the dye obtained from red fruit tea showed inferior results, as the transmittance obtained at these concentrations was higher than that found for concentration (1). Therefore, it is evident that concentration directly influences transmittance and, consequently, the absorbance of the dye.

3.2 Electrical Evaluation of Dye-Sensitized Nanocrystalline Solar Cell (DSSC)

The characterization of the photovoltaic cell produced with red fruit tea dye (1) was carried out by measuring the voltage (V) and current (I). In this way, the I-V curve was obtained at different resistance (R) values, as observed in Figure 4.

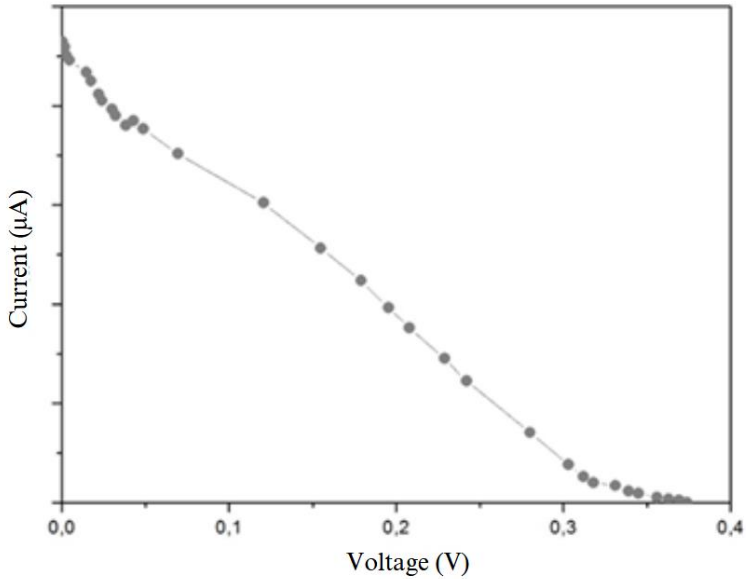
The I-V curve (Figure 4) showed similarity to the study conducted by Azevedo and Cunha (1991). It was possible to determine the power generated as a function of the applied resistance (Figure 5), an important data point regarding the application of photovoltaic cells, according to the authors.

Through the analysis of the results presented in Figure 5, it was possible to determine the maximum power (Pmax) for the fabricated 25 mm² cell as a function of the load resistance (Rload), where the Pmax found was equivalent to 8 μW for the Rload of 700 Ω, resulting in a Pmax of 3.2 μW cm⁻².

Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

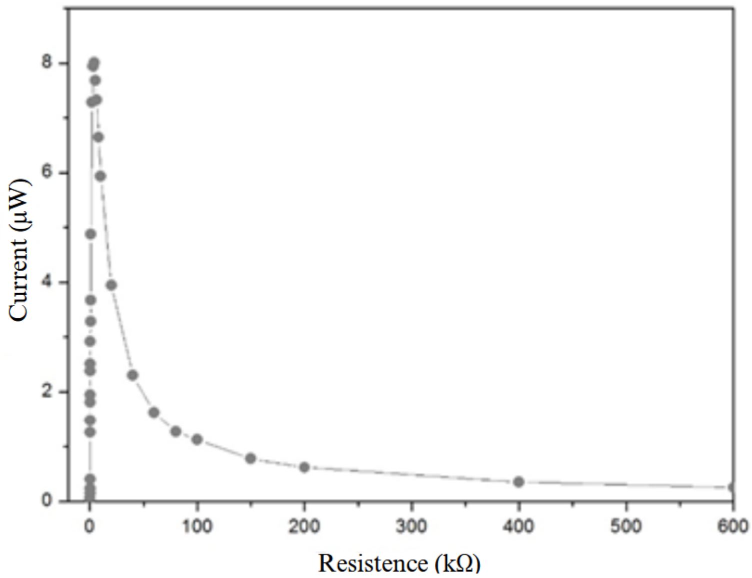
ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Figure 4 - I-V Curve of the Fabricated DSSC.



Source: The authors, 2024.

Figure 5 - Power Curve as a Function of Load of the Fabricated DSSC.



Source: The authors, 2024.

The electrical characterizations obtained showed results inferior to other studies that used natural extracts containing anthocyanin. The efficiency obtained for the tea in this study presented maximum power values below those found by Patrocínio and Iha (2010), who reported Pmax values of 1600 μW cm-2 for blackberry, 1500 μW cm-2 for raspberry, and 810 μW cm-2 for blueberry. However, according to Kim et al. (2013), a value of 4248 μW cm-2 was found for jabuticaba. This can be attributed to the material used, considering that the studies utilized fresh fruits to obtain the dyes, which allows for greater efficiency.

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Nevertheless, it was observed that there is a lack of methodologies for an effective comparison of the results of the studies already conducted. This can be attributed to variations in laboratory procedures and even the origin of the compound, considering that, being organic dyes, they are susceptible to environmental influences such as: the climatic conditions of the region, soil composition, genetic variation of the plant, among other factors.

Brazil has an energy matrix based on hydroelectric and thermoelectric sources. However, due to its great potential for energy production through photovoltaic cells, some studies are conducted within the country, such as the research by Feitosa et al. (2018), which evaluated the influence of climate on photovoltaic energy production in the state of Maranhão. The authors analyzed the correlation between solar incidence and precipitation in the Amazon and Cerrado regions and found that Cerrado zones have a greater potential for photovoltaic energy production compared to the Amazon, considering the conditions of lower precipitation rates.

Therefore, in order to reduce the cost of manufacturing and producing photovoltaic cells and panels, it is essential to conduct studies that consider different materials, such as the present study, thereby increasing the competitiveness of this energy matrix. This way, it will be possible to expand the population's access to technology and contribute to the reduction of greenhouse gas emissions from thermoelectric plants, which are still widely used globally.

4 CONCLUSION

It was possible to verify that there is a variation in transmittance depending on the compounds of the different dyes analyzed and their concentrations. It is concluded that the preliminary analysis of transmittance or absorbance of the dyes, aiming for low transmittance and consequently higher absorbance for application in DSSCs, is an effective technique. Given that Brazil is a country with vast biodiversity, it has significant potential for exploring new compounds with unknown efficiency. The technique employed demonstrates, in a quick and cost-effective manner, the efficiency estimation of DSSCs.

The photovoltaic cell produced from red fruit tea exhibited a maximum power of 8 µW for a 700 Ω load, a value lower than those found in the literature. This discrepancy can be attributed to the lack of methodological uniformity, as well as the different materials used as dyes.

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

REFERÊNCIAS

AGNALDO, J. S.; BASTOS, J. B. V.; CRESSONI, J. C.; VISWANATHAN, G. M. Células solares de TiO2 sensibilizado por corante. **Revista Brasileira de Ensino de Física**, v. 28, n. 1, p. 77-84, 2006.

AHMED, A. A.; NAZZAL, M. A.; DARRAS, B. M.; DEIAB, I. M. Global warming potential, water footprint, and energy demand of shared autonomous electric vehicles incorporating circular economy practices. **Sustainable Production and Consumption**, v. 36, p. 449-462, 2023.

ALONSO, E.; SHERMAN, A. M.; WALLINGTON, T. J.; EVERSON, M. P.; FIELD, F. R.; ROTH, R.; KIRCHAIN, R. E. Evaluating rare earth element availability: A case with revolutionary demand from clean technologies**. Environmental Science & technology**, v. 46, n. 6, p. 3406-3414, 2012.

ANDUALEM, A.; SOLOMON, D. Review on Dye-Sensitized Solar Cells (DSSCs). **Journal of Heterocyclics**, v. 1, n. 1, p. 6, 2018.

AZEVEDO, M.; CUNHA, A. Fazer uma célula fotovoltaica. **Rev. Physical on Stage**, v. 2, n. 4, p. 1-3, 1991.

CALOGERO, G.; DI MARCO, G.; CARAMORI, S.; CAZZANTI, S.; ARGAZZI, R.; BIGNOZZI, C. A. Natural dye senstizers for photoelectrochemical cells. **Energy & Environmental Science**, v. 2, n. 11, p. 1162-1172, 2009.

FEITOSA, F. E. C. S.; BELO, R. C. R.; SANTOS, J. R. N.; DE ARAÚJO, M. L. S.; DOS SANTOS, J. S.; SILVA, F. B. Influência das Mudanças de Tempo e Variabilidade Climática sobre a Produção de Energia Fotovoltaica no Estado do Maranhão. **Revista Brasileira de Geografia Física**, v. 10, n. 6, p. 1959-1973, 2017.

FREITAS, F. E. **Célula solar de SnO2/TiO2 preparada por spray-pirólise ativada com corante orgânico.** 150 f. Dissertação (Mestrado), Universidade Estadual Paulista (Unesp), Ilha Solteira, 2006.

GONG, J.; LIANG, J.; SUMATHY, K. Review on dye-sensitized solar cells (DSSCs): Fundamental concepts and novel materials. **Renewable and Sustainable Energy Reviews**, v. 16, n. 8, p. 5848-5860, 2012.

KIM, H. J.; KIM, D. J.; KARTHICK, S. N.; HEMALATHA, K. V.; RAJ, C. J.; OK, S.; CHOE, Y. Curcumin dye extracted from Curcuma longa L. used as sensitizers for efficient dye-sensitized solar cells. **International Journal of Electrochemical Science**, v. 8, n. 6, p. 8320-8328, 2013.

LAERA, L. H. N. Mudanças Climáticas e as Responsabilidades, Atribuições e Ações do Poder Público na Cidade do Rio de Janeiro. **Revista de Direito da Cidad**e, v. 5, n. 2, p. 137-152, 2013.

LIMA, G. A. M.; SOUZA, V. O.; LOPES, R. S. Emerging technologies for photovoltaic solar cell production: a review. **Research, Society and Development**, v. 11, n. 17, p. e139111736068, 2022.

LOPES, T.; XAVIER, M.; QUADRI, M. G.; QUADRI, M. Antocianinas: uma breve revisão das características estruturais e da estabilidade. **Current Agricultural Science and Technology**, v. 13, n. 3, p. 291-297, 2007.

MAEDA-YAMAMOTO, M. et al. Chemical analysis and acetylcholinesterase inhibitory effect of anthocyanin-rich red leaf tea (cv. Sunrouge). **Journal of the Science of Food and Agriculture**, v. 92, n. 11, p. 2379-2386, 2012.

MURAKOSHI, K;, KOGURE, R.; WADA, Y.; YANAGIDA, S. Fabrication of solid-state dye-sensitized TiO2 solar cells combined with polypyrrole. **Solar Energy Materials and solar cells**, v. 55, n. 1-2, p. 113-125, 1998.

O'REGAN, B.; GRÄTZEL, M. A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films. **Nature**, v. 353, n. 6346, p. 737-740, 1991.

PATROCÍNIO, A. O. T.; MURAKAMI IHA, N. Y. Em busca da sustentabilidade: células solares sensibilizadas por extratos naturais. **Química Nova**, v. 33, n. 3, p. 574-578, 2010.

PETER, L. M. The gratzel cell: where next? **The Journal of Physical Chemistry Letters**, v. 2, n. 15, p. 1861-1867, 2011.

REIS, L. B. Geração de Energia Elétrica. 2 ed. Barueri, SP: Manole, 2011.

ROY, S.; RHIM, J.-W. Anthocyanin food colorant and its application in pH-responsive color change indicator films. **Critical Reviews in Food Science and Nutrition**, v. 61, n. 14, p. 2297-2325, 2021.

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

SHARMA, R.; SHARMA, A.; AGARWAL, S.; DHAKA, M. S. Stability and efficiency issues, solutions and advancements in perovskite solar cells: A review. **Solar Energy**, v. 224, n. 15, p. 516-535, 2022.

SOLANGI, K. H.; ISLAM, M. R.; SAIDUR, R.; RAHIM, N. A.; FAYAZ, H. A review on global solar energy policy. **Renewable and sustainable energy reviews**, v. 15, n. 4, p. 2149-2163, 2011.

SONAI, G. G.; MELO JUNIOR, M. A.; NUNES, J. H.; MEGIATTO JR, J. D.; NOGUEIRA, A. F. Solar cells sensitized with natural dyes: an introductory experiment about solar energy for undergraduate students. **Química Nova**, v. 38, n. 10, p. 1357-1365, 2015.

SUN, L.; CHEN, Y.; SUN, M.; ZHENG, Y. Organic solar cells: physical principle and recent advances. **Chemistry - An Asian Journal**, v. 18, n. 5, p. e202300006, 2023.

VARELLA, F. K. O. M.; CAVALIERO, C. K. N.; SILVA, E. P. D. Energia solar fotovoltaica no Brasil: Incentivos regulatórios. **Revista Brasileira de Energia**, v. 14, n. 1, p. 9-22, 2008.