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Article

Performance evaluation of a flat-plate solar collector with polished, unpolished, and erbium Phthalocyanine-Coated Glass

Evaluación del rendimiento de un colector solar de placa plana con vidrio pulido, sin pulir y recubierto con ftalocianina de erbio

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Abstract

The study evaluates the impact of Erbium Phthalocyanine [ErPc] coatings on flat-plate solar heaters with different glass covers. SEM analysis revealed high-purity ErPc with nanospherical morphology, enhancing solar radiation absorption. However, agglomerates and nanowires may affect optical and thermal properties, highlighting the need for improved film uniformity. Solar heaters with ErPc coatings showed higher initial absorber plate temperatures, suggesting enhanced energy capture, but also exhibited temperature declines over time, indicating complex heat transfer dynamics. Polished glass allowed greater solar transmittance but increased thermal emissivity and heat loss, while unpolished glass better retained heat despite lower initial transmittance. The ErPc film modulated thermal response, possibly absorbing infrared radiation, but its full effect requires further study. The findings suggest that selective coatings like ErPc could improve solar heater efficiency, though optimizing film deposition, thorough thermal characterization, and long-term performance assessments under varying conditions are necessary for practical application.

Solar water heater, Thin film deposition, Ultrasonic spray pyrolysis

Area: Dissemination of and universal access to science

Resumen

El estudio analiza el impacto de recubrimientos de ftalocianina de erbio [ErPc] en calentadores solares de placa plana con diferentes vidrios. El análisis SEM mostró ErPc de alta pureza con morfología nano esférica, que mejora la absorción solar. Sin embargo, aglomerados y nano hilos pueden afectar las propiedades ópticas y térmicas, por lo que se requiere mayor uniformidad en la película. Los calentadores con ErPc presentaron temperaturas iniciales más altas en la placa absorbedora, indicando mejor captación energética, pero luego hubo una disminución térmica, reflejando dinámicas complejas de transferencia de calor. El vidrio pulido permitió mayor transmitancia solar, pero aumentó las pérdidas térmicas, mientras que el vidrio sin pulir retuvo mejor el calor pese a menor transmitancia. La película de ErPc moduló la respuesta térmica, posiblemente absorbiendo infrarrojo, aunque su efecto completo requiere más estudio. Estos resultados sugieren que ErPc puede mejorar la eficiencia solar, pero se necesitan optimizaciones y evaluaciones a largo plazo para su aplicación.

Calentador de agua solar, depósito de películas delgadas, espray pirolisis ultrasónico

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Introduction

In recent decades, solar thermal energy systems have surged in importance, driven by an urgent call to address climate change, a strong desire to reduce our dependence on fossil fuels, and an ever-growing need for sustainable energy sources. Among the most popular technologies for capturing the sun's energy are flat-plate solar collectors [FPCs], celebrated for their elegant simplicity, affordability, and remarkable efficiency in providing hot water [1]. These systems have become the focus of extensive research aimed at optimizing their thermal performance through innovative materials, coatings, and geometric designs [2,3].

At the heart of these systems lies the glass cover, an essential component that directly influences overall efficiency. This glass acts as a welcoming gateway for solar radiation while diligently minimizing heat loss to the surrounding environment through convection and radiation [4]. The type of glass used can greatly vary in treatment and optical properties, profoundly impacting its capacity to capture solar energy and curb thermal losses. Common choices include polished glass, known for its sleek and shiny surface, unpolished glass with its subtle texture, and the more recent innovation of glass coated with advanced thin films such as phthalocyanine, which has shown remarkable potential for enhancing the efficacy of solar devices [2].

Phthalocyanine, an intriguing organic compound from the azo dye family, has captured the attention of scientists with its remarkable optical and electronic characteristics, making it an ideal candidate for both photovoltaic devices and solar thermal collectors [5]. When thin films of phthalocyanine are applied to glass, they serve as a selective barrier that not only permits a generous amount of solar radiation to enter but also minimizes thermal emissions, ultimately boosting the system's thermal efficiency [6].

Polished glass, a staple choice for FPC covers, boasts a smooth and strikingly transparent facade that allows a maximum influx of solar energy [7]. However, its notable drawback lies in its high thermal emissivity, which can lead to significant heat loss to the surroundings [8].

In contrast, unpolished glass features a rough, opaque texture that may hinder transmissivity but provides improved thermal retention due to lower emissivity [8,9].

The decision between polished and unpolished glass revolves around the delicate balance of maximizing solar radiation capture while minimizing thermal losses [4,10].

Research has illustrated that in colder climates, unpolished glass might prove to be more favourable due to its heat-retaining capabilities. Conversely, in warmer regions, polished glass often emerges as the superior choice, allowing for a vibrant influx of solar energy [10].

Moreover, phthalocyanine films, celebrated for their strong absorption of solar radiation, function as selective filters. They permit the passage of visible sunlight while effectively curtailing infrared thermal emissions, resulting in enhanced heat retention [11].

The FPCs, introducing a layer of phthalocyanine onto the glass presents an exciting opportunity to elevate system efficiency by mitigating thermal losses without compromising the glass's solar radiation transmission [11]. Recent studies have unveiled that such coatings could potentially augment the thermal efficiency of solar systems by as much as 20%, marking a momentous stride in the quest to optimize solar energy technologies [8].

Methodology

Deposition of Erbium Phthalocyanine on Polished and Unpolished Glass:

The meticulous process of conducting a "Performance Evaluation of a Flat-Plate Solar Collector with Polished, Unpolished, and Phthalocyanine-Coated Glass" begins with four carefully selected glass plates, each measuring 14 cm × 24 cm, specifically designed to capture and absorb solar radiation.

The journey begins with the first glass plate, which undergoes a rigorous surface polishing process using a 600-grit wet sandpaper. For an intensive 80 minutes, the glass surface was polished with precision, moving in a single, consistent direction from the top to the bottom.

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This process involved meticulously sanding from left to right, progressively advancing downward until the glass's bottom edge was reached, and then seamlessly starting again at the top. This careful repetition ensured a flawlessly smooth surface, with the sandpaper continuously soaked in water to maintain its effectiveness throughout. The same process was meticulously replicated on a second glass plate, which would eventually receive the phthalocyanine application.

Once the glass plates were expertly prepared, one unpolished and one polished plate were set aside for the application of erbium phthalocyanine. The deposition of phthalocyanine was executed with finesse using a nano-mister, which was affixed to a 3D printer, orchestrating a zigzag pattern that danced across the 14 cm × 24 cm glass plate [See Figure 1].

Box 1

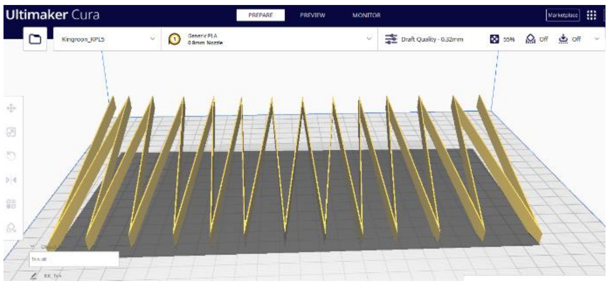

Figure 1

Movement Design for Depositing Phthalocyanine on the 24 × 14 cm Glass Plates.

This innovative deposition design was crafted with the help of Fusion 360 and then seamlessly imported into a 3D printing preparation software, Cura. Once the design was perfected, 2 grams of Erbium Phthalocyanine were meticulously dispersed in 44 ml of 98% grade alcohol using an ultrasonic bath [see Figure 2a]. This thoughtfully prepared mixture was then skillfully applied using the nano-mister installed on the 3D printer, ensuring an even distribution of the solution across the glass plates.

Before applying the phthalocyanine solution, each glass plate underwent a thorough decontamination process with acetone [see Figure 2b] and alcohol. These cleaning agents were applied to absorbent paper, and the glass was meticulously cleaned to eradicate any smudges or fingerprints, ensuring a pristine surface.

This critical decontamination step was executed on all four glass plates, with particular attention given to the unpolished and polished plates designated for the coating.

Box 2

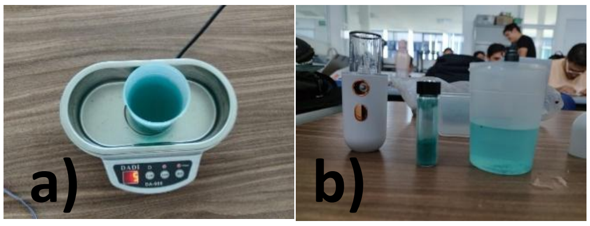

Figure 2

a] Phthalocyanine solution in alcohol in an ultrasonic bath, b] materials for deposition of thin films of erbium phthalocyanine.

Following the decontamination, the Kingroon KP5L 3D printer was readied for action by preheating its bed to a warm 65°C and leveling it to a height of 2 cm from the nano-mister. The extruder and its cooling fan were intentionally disabled to prevent any disturbance during the delicate application process. The travel speed of the printer was manually calibrated to 50% for optimal control. With the setup complete, a glass plate was positioned on the heated bed, and the application process commenced, maintaining a consistent flow for 120 minutes [see Figure 3].

Box 3

Figure 3

Thin film deposition of erbium phthalocyanine dispersed in alcohol.

The results of this intricate process are strikingly illustrated in Figure 4, showcasing the deposition of phthalocyanine on both polished and unpolished glass plates.

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The zigzag pattern of the deposit is vividly reflected in the sunlight, while the attenuation effects of the phthalocyanine coating are markedly more pronounced on the polished glass surface.

Box 4

Figure 4

Deposition Pattern of erbium phthalocyanine

Fabrication of the Flat-Plate Solar Collector

Following the meticulous deposition of phthalocyanine onto each of the two glass plates, the next critical phase in fabricating the flat-plate solar collector began. This stage involved constructing a robust base designed to securely hold the glass plates, which would subsequently be adhered and sealed tightly in place, as depicted in Figure 5a and 5b.

Box 5

Figure 5

Gluing the glass plate to the base containing the copper tubing coil of the flat-plate solar collector.

The solar collector was ingeniously designed using a standard one-gallon plastic jug, which served as the main housing for the water accumulator, alongside Styrofoam insulation, a stable supporting base, and intricate copper tubing for fluid circulation. The copper tubing, essential for transferring heat, was carefully glued to a solid aluminium base.

This aluminium platform provided optimal conductivity and stability, ensuring that the glass absorber plates were securely positioned atop it. Each of the four glass plates—two polished and two phthalocyanine-coated—was installed with precision, ensuring a snug fit that maximized both structural integrity and thermal performance.

To enhance thermal retention within the system, each gallon jug was encased in Styrofoam insulation. This insulating layer served a dual purpose: it minimized heat loss to the surrounding environment and maintained a consistently high temperature for the water contained within.

In addition to the base construction and insulation, the process also required careful planning for fluid dynamics. Two strategically placed holes were drilled into the upper portion of each jug, facilitating the connection of the copper tubing. This design allowed for a continuous flow of water in and out of the system, ensuring effective heat exchange. The copper tubing, arranged in a coil to maximize surface area exposure, enabled the efficient circulation of water, which would absorb solar heat through the glass plates.

The entire assembly was meticulously designed to ensure practicality and functionality, prioritizing thermal efficiency and ease of use, as illustrated in Figure 6. This comprehensive approach aimed at creating an optimal flat-plate solar collector that harnessed solar energy effectively while maintaining ideal thermal conditions for the collected water.

Box 6

Figure 6

Solar collector with its respective glass plate, which was positioned on an aluminum base with a copper tube coil.

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Results

Figure 7a showcases the intricate details captured in the mass spectrometry characterization, revealing the striking molecular ion of erbium phthalocyanine at 679 m/z [12], [13]. In figure 7 a comprehensive array of characterizations of ErPc unfolds, shedding light on the meticulous synthesis and purification processes that yield an exceptionally high-quality ErPc powder. Figure 7b presents the Fourier-transform infrared [FT-IR] spectrum of ErPc, where the phthalocyanine macrocycles resonate with a symphony of vibrational modes between 400 and 1800 cm⁻¹. The peaks in this spectrum are often described as an IR fingerprint, each distinct peak reflecting the unique characteristics of phthalocyanine [6].

Within the spectrum, peaks around 400–600 cm⁻¹ signify out-of-plane C–C–C bending, while peaks ranging from 700–735 cm⁻¹ highlight the out-of-plane C–H vibrations, evoking a sense of structural intricacy. Additionally, the peaks located between 750–1040 cm⁻¹ correlate with outer-plane C–H bending, and the subtle in-plane C–H bending manifests at 1050–1080 cm⁻¹. A delicate, low-intensity band nestled between 1396–1407 cm⁻¹ reveals the vibrations of the C=C–N group, which comprises interatomic fragments from pyrrole and nitrogen. Meanwhile, strong bands between 1300–1350 and 1400–1500 cm⁻¹ resonate with the stretching vibrations of the isoindole segment, which includes the elegant structures of pyrrole and benzene residues.

Mass spectrometry serves as a powerful validating tool, confirming the presence of the characteristic molecular ion of erbium phthalocyanine at 679 m/z and attesting to the successful synthesis of this compound. This analytical technique excels in the identification and characterization of organic compounds, allowing for precise determinations of molecular mass and composition. The compelling results illustrate that the synthesis and purification of erbium phthalocyanine lead to a high-quality powder, primed and ready for further research and applications [14].

The analysis via Fourier-transform infrared [FT-IR] spectroscopy unfolds a narrative of molecular vibrations that eloquently describe the uniqueness of erbium phthalocyanine. The peaks observed within the 400–1800 cm⁻¹ range correspond to diverse vibrational modes, characteristic of the distinct phthalocyanine structure [14]. These vibrational modes play a crucial role in identifying and confirming the presence of specific functional groups within the molecule. The peaks perceived in the FT-IR spectrum align seamlessly with those typical of phthalocyanine, presenting an unmistakable fingerprint that affirms its molecular identity [15].

The peaks that signify out-of-plane C–C–C bending and out-of-plane C–H vibration emerge as evidence of phthalocyanine rings nestled within the ErPc molecular structure. Alongside this, the peaks related to C–H bond bending and vibration eloquently suggest the existence of hydrocarbon groups entwined in the intricate structure. Moreover, the low-intensity band at 1396–1407 cm⁻¹ resonates with interatomic fragments of pyrrole and nitrogen, further substantiating the structure of erbium phthalocyanine. The detection of stretching vibrations from the isoindole segment magnifies the presence of pyrrole and benzene residues, weaving a richer narrative around the ErPc molecule [14], [15].

Mass spectrometry validates the presence of the characteristic molecular ion, while the FT-IR spectrum unveils the specific molecular vibrations, painting a vivid picture of the elegant complexities associated with erbium phthalocyanine.

Box 7

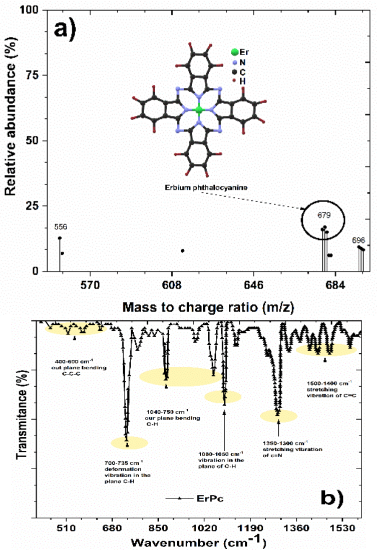

Figure 7

Title: a] Mass spectrum of ErPc powder, and b] FT-IR transmittance spectrum of an ErPc thin film deposited on a crystalline silicon substrate.

Figure 8 vividly captures the absorption spectra derived from the Erbium Phthalocyanine [ErPc] thin film elegantly deposited on a glass substrate. The striking Soret band [B] emerges between 339–391 nm, dancing within the ultraviolet spectrum and showcasing the unique characteristics of the phthalocyanine molecule. This absorption feature, a hallmark of π–π* transitions, illustrates the dynamic excitation of electrons within the molecule's intricate orbital structures. Known for its exceptionally high molar absorptivity, the B band serves as a mirror reflecting the rich electronic architecture and the extensive conjugation length inherent to the phthalocyanine macrocycle.

In addition to this captivating Soret band, the Q band makes its presence felt, gracing the visible spectrum with a range from 550 to 750 nm. This band, too, is steeped in π–π* transitions, enriching our understanding of the electronic nuances of the ErPc molecule. Interestingly, the Q band may exhibit a phenomenon known as Davydov splitting, where it divides into multiple sub-bands. This intriguing effect arises from the interplay of intermolecular interactions within the crystal's lattice structure, transforming electronic transitions into a cascade of spectral signatures. In this particular evaluation, two distinct sub-bands have been unveiled: Q_1, which gracefully spans from 608 to 639 nm, and Q_2, ranging from 654 to 677 nm [16]–[18].

Box 8

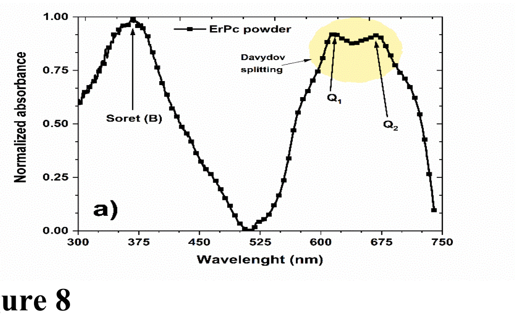

Figure 8

Absorption spectrum of the erbium phthalocyanine thin film deposited on a glass substrate.

Figure 9 captures the intricate beauty of scanning electron microscopy [SEM] micrographs, showcasing the Erbium Phthalocyanine [ErPc] thin films meticulously deposited on crystalline silicon substrates. The visual representation reveals a captivating nanosphere-like morphology, with particles exhibiting diverse sizes ranging from a delicate 18 to an impressive 196 nanometers [12], [6].

In Figure 9a the micrograph presents a stunning panorama of nanospheres, uniformly scattered across the entire substrate surface like a pristine blanket of tiny pearls. This carefully orchestrated deposition process has engendered a harmonious arrangement of ErPc particles, culminating in a smooth and consistent thin film. Such uniformity is paramount, as it ensures not only aesthetic appeal but also reliable performance characteristics essential for various applications.

In contrast, Figure 9b unveils a close-up of specific regions where agglomerations of ErPc nanospheres come into view. These clusters, reminiscent of playful constellations, form due to the nuances of the deposition technique employed. Factors such as the intricate dynamics of deposition rate, the delicate dance of solvent evaporation, and the interactions at the substrate surface all play pivotal roles in creating these fascinating formations. While these agglomerations might introduce a hint of heterogeneity, they also possess the potential to influence crucial material properties, such as charge transport and optical response, adding layers of complexity to the thin film’s behavior [19].

The art of controlling and optimizing the deposition process cannot be overstated; it serves as a gateway to achieving the desired film morphology while minimizing the occurrence of these intriguing clusters. By meticulously fine-tuning the deposition parameters and techniques, one can unlock the potential for enhanced uniformity, steering the creation of thin films toward unrivaled efficiency and performance in practical applications.

Box 9

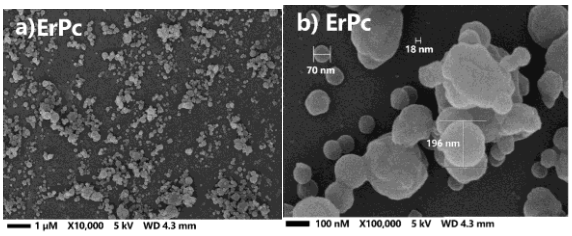

Figure 9

SEM micrographs of ErPc thin films deposited on silicon substrates.

In Figure 10a the SEM micrograph reveals the pristine surface of the glass substrate, showcasing it in its untouched state, devoid of any erbium phthalocyanine deposition.

The clarity of the image accentuates the glass's smoothness, serving as a stark contrast to the subsequent figures.

Moving to Figure 10b, the transformation is striking; here, the deposition of erbium phthalocyanine on an unpolished glass substrate comes to life. This micrograph displays a captivating panorama of ErPc particles, illustrating a uniform distribution that blankets the entire surface like a delicate layer of frost. Yet, amidst this harmonious spread, clusters of ErPc particles emerge, forming agglomerations that hint at the complexity of the deposition process. In this image, one can also discern the presence of elegant nanowires, elegantly sculpted by ErPc crystals, adding a dynamic texture to the substrate [20].

Figure 10c offers a glimpse into the polished glass substrate, where the effects of the polishing process are prominently displayed through distinct striations. These visible lines echo the craftsmanship involved in preparing the glass, revealing a surface that is both refined and intricate. Here, the deposition of ErPc manifests as a carpet of agglomerations, blanketing the substrate while small ErPc nanospheres peek through in select areas, contributing to the visual complexity. It is noteworthy that the polishing process has left behind microcracks on the glass surface—minute imperfections that contrast with the otherwise sleek appearance.

Nevertheless, the nanoscale size of the ErPc particles ensures that the deposition has effectively cloaked these imperfections, resulting in comprehensive coverage over the entire area.

Box 10

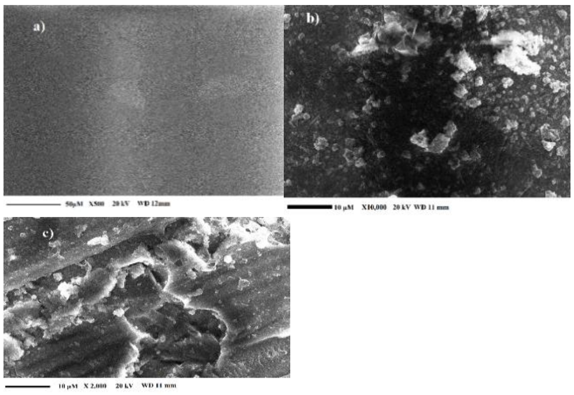

Figure 10

SEM micrographs of ErPc films deposited on: a] glass substrate as reference, b] unpolished glass, and c] polished glass.

The data captured in Figures 11a–d vividly illustrates the thermal performance of a flat-plate solar collector under varying glass configurations, all while maintaining a consistent 3-liter water level.

Figure 11a reveals the dynamics of the solar collector outfitted with a polished glass plate, void of erbium phthalocyanine deposition. At the outset of the experiment [time 0], the water temperature is a crisp 22.4 °C, while the polished glass plate basks in the sun's warmth at 43 °C. Over the next hour, the water temperature embarks on a gradual ascent, finally reaching a mild 30 °C. In stark contrast, the plate temperature dances with fluctuations, initially soaring to a peak of 48 °C within the first ten minutes before gracefully descending to 40.4 °C by the conclusion of the test. Notably, throughout this period, the plate maintains a steady superiority in temperature compared to the water.

In Figure 11b, the scene shifts to polished glass adorned with erbium phthalocyanine deposition. Here, the journey begins with the water temperature at a cooler 22 °C, while the plate revels in a higher initial temperature of 52 °C. The water warms steadily, climbing to 29.1 °C over the 60 minutes.

Meanwhile, the plate temperature ebbs and flows with minor fluctuations, concluding at 41 °C. Consistently, throughout this testing phase, the plate temperature remains strikingly elevated compared to its aquatic counterpart.

Turning to Figure 11c, we encounter the unpolished glass panel, again devoid of phthalocyanine deposition. At time 0, the water sets off at a slightly higher initial temperature of 22.6 °C against a starting plate temperature of 47 °C. Over the course of the measurement, the water temperature steadily rises, ultimately reaching 28.9 °C after an hour. The plate temperature, amidst a subtle display of fluctuations, begins robust but settles at 44 °C, solidifying its status as consistently warmer than the water through the entire test duration.

Finally, Figure 11d examines the combination of unpolished glass with the addition of erbium phthalocyanine deposition. The initial readings show the water temperature at a gentle 22 °C, while the plate basks at 52 °C.

As the experiment unfolds, the water temperature gradually edges up to 28.9 °C by the end of the 60 minutes.

Meanwhile, the plate temperature experiences a slight decline to 42.2 °C, with subtle fluctuations along the way. Once again, the plate exhibits a predominant warmth compared to the water temperature throughout the measurement period [21]-[23].

Box 11

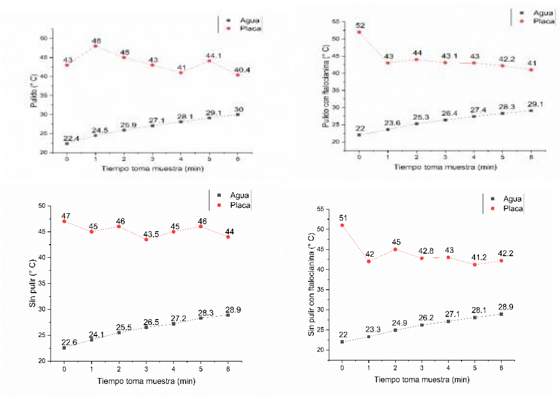

Figure 11

Title: Characterizations of the flat-plate solar water heater with different glass plates and a 3-liter water container: a] polished glass without erbium phthalocyanine deposition, b] polished glass with erbium phthalocyanine deposition, c] unpolished glass without erbium phthalocyanine deposition, and d] unpolished glass with erbium phthalocyanine deposition.

Figures 12a–d provide a detailed exploration of the thermal characteristics of a flat-plate water heater, calibrated to a water level of 6 liters.

In Figure 12a, the polished glass plate without erbium phthalocyanine deposition sets the stage. At the onset of the experiment [time 0], the water temperature begins at a snug 28 °C while the plate revels in a warm 45 °C. Over the course of the next hour, the water temperature gently climbs to 31.5 °C.

The plate temperature, however, showcases a dynamic display: it ascends to a peak of 47 °C at the 5-minute mark before gradually decreasing to 43.3 °C at the experiment's conclusion. Throughout this observation, the plate temperature consistently outshines the water temperature.

Figure 12b shifts to the polished glass enhanced with erbium phthalocyanine deposition. Here, the initial water temperature registers at a slightly warmer 30.2 °C, while the plate temperature starts at a robust 49 °C. As the minutes pass, the water temperature experiences a modest rise, reaching 33.2 °C at the 60-minute mark. Meanwhile, the plate temperature dances between 44.5 °C and 49 °C, closing the measurement period at 46.1 °C. Once again, the plate maintains a higher temperature compared to the water throughout the entire evaluation.

The focus moves to Figure 12c, showcasing the unpolished glass devoid of any phthalocyanine coating. The initial conditions reveal a water temperature of 28 °C alongside a starting plate temperature of 45 °C. Following the hour, the water temperature steadily increases to 31.1 °C, while the plate temperature experiences a slight dip from 45 °C to 44 °C, punctuated by minor fluctuations. The plate remains consistently elevated above the water temperature throughout this segment. Figure 12d presents the unpolished glass coated with erbium phthalocyanine. At the outset, the water temperature reads 29.7 °C, and the plate temperature basks at 50 °C. As the time progresses, the water temperature creeps upward to 32.6 °C by the end of the 60 minutes. The plate temperature, starting at its peak of 50 °C, gradually declines to 44.7 °C by the experiment's close, capturing a peak of 48.2 °C at the 40-minute mark. Consistently throughout this measurement, the plate temperature remains significantly higher than the water temperature, solidifying its pivotal role in enhancing thermal retention.

Box 12

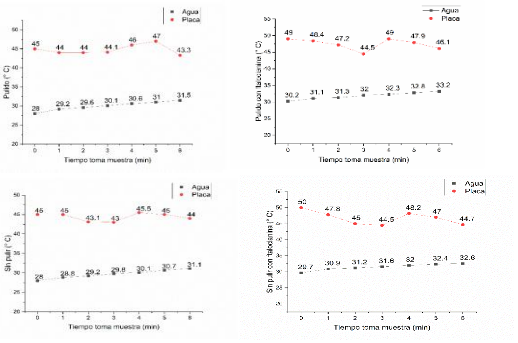

Figure 12

Characterizations of the flat-plate solar water heater with different glass plates and a 6-liter water container: a] polished glass without erbium phthalocyanine deposition, b] polished glass with erbium phthalocyanine deposition, c] unpolished glass without erbium phthalocyanine deposition, and d] unpolished glass with erbium phthalocyanine deposition.

Figures 13a–d vividly showcase the thermal dynamics of the flat-plate water heater, tailored to hold a generous 9 liters of water, while highlighting various glass types and coatings employed in the experiment.

Figure 13a depicts the polished glass devoid of erbium phthalocyanine deposition. At the outset, the water temperature is a cool 24 °C, while the shimmering surface of the plate registers a warmer 42 °C. As time unfolds, the water temperature gradually climbs to a modest 26.3 °C after a span of 60 minutes. The plate temperature exhibits a series of fluctuations, dancing up to a peak of 45.9 °C at the 40-minute mark before descending to 38.1 °C by the end of the hour. Notably, throughout this thermal journey, the plate maintains a consistent dominance over the water temperature, capturing the sun's warmth more effectively.

Figure 13b introduces the polished glass now enhanced by the application of erbium phthalocyanine. Here, the initial water temperature begins at a slightly higher 25.5 °C, with the plate radiating heat at 45 °C. Over the course of 60 minutes, the water temperature experiences a gentle ascent to 27.9 °C, while the plate temperature fluctuates between 45 °C and 46.8 °C, ultimately settling at a cooler 40 °C. During this evaluation, the plate temperature remains steadfastly higher than that of the water, emphasizing its effectiveness in harnessing solar energy.

Figure 13c reveals the story of unpolished glass without the phthalocyanine coating, where the experiment begins with the water at a baseline of 24.6 °C and the plate at a warm 45 °C. After one hour, the water temperature rises to 26.8 °C, yet the plate, once holding steady, cools down to 36.8 °C, illustrating some variability in its thermal retention. Despite this decrease, the plate temperature continues to hover above that of the water, showcasing its lasting ability to absorb heat. In Figure 13d, the unpolished glass now boasts the addition of erbium phthalocyanine.

The initial conditions present a water temperature of 26.5 °C and a plate temperature radiating at 48.7 °C. As the minutes tick by, the water temperature swells to 28.5 °C by the 60-minute mark, while the plate temperature sees a slight decline to 48 °C. Remarkably, it peaks at an impressive 50 °C at the 20-minute mark before stabilizing.

Throughout this testing period, the plate temperature reigns supreme, far surpassing the water's warmth and underscoring the efficiency of the phthalocyanine coating.

Box 13

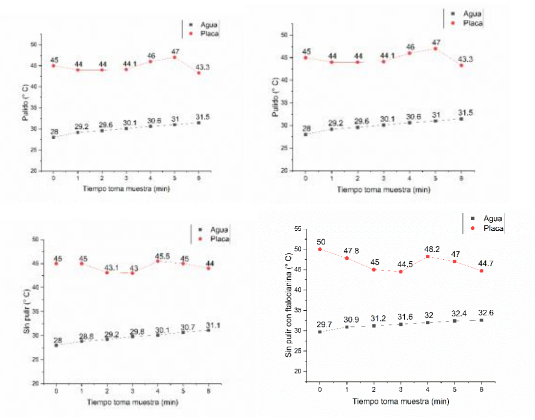

Figure 13

Title: Characterizations of the flat-plate solar water heater with different glass plates and a 9-liter water container: a] polished glass without erbium phthalocyanine deposition, b] polished glass with erbium phthalocyanine deposition, c] unpolished glass without erbium phthalocyanine deposition, and d] unpolished glass with erbium phthalocyanine deposition.

Conclusions

The composition of a flat-plate solar heater's cover material, along with the application of selective coatings, plays a critical role in determining its overall performance. A thorough analysis of Erbium Phthalocyanine [ErPc] established that the material is of high purity, boasting a nanospherical morphology as observed through Scanning Electron Microscopy [SEM].

This structure suggests a significant surface area, which is essential for capturing solar radiation effectively. However, the presence of agglomerates and nanowires seen in some deposits may influence the optical and thermal properties of the coating. Consequently, it's important to control a broader range of parameters to enhance the uniformity of the film.

When assessing the performance of solar heaters with varying cover types, it becomes evident that the incorporation of ErPc correlates with a trend toward achieving a higher initial temperature of the absorber plate.

This could imply enhanced efficiency in harnessing solar energy. Nevertheless, the data also reveals a consistent decline in the plate's temperature during the ErPc tests, suggesting that heat may be transferred more efficiently to the water or that different heat dissipation mechanisms are in play compared to systems without coatings.

In detail, polished glass, characterized by its comparatively high transmittance within the solar spectrum, effectively allows radiation to penetrate into the chamber. However, this increased transmittance may also lead to higher thermal emissivity, potentially resulting in greater long-term heat losses.

In contrast, unpolished glass—though it exhibits slightly reduced initial transmittance—may prove more effective in retaining heat due to its lower emissive properties, particularly evident in the later stages of measurement.

The thin ErPc film applied to both polished and unpolished glass seems to modulate the thermal response of the system. The elevated surface temperature observed on the plate suggests greater absorption of solar radiation, possibly within the infrared spectrum, as indicated by preliminary observations.

However, the subsequent drop in plate temperature over time prompts a re-evaluation of the energy balance considerations, encompassing factors such as the heat transferred to the water, convection and radiation losses, and the specific spectral characteristics of the ErPc film in the thermal emission range of the absorber.

This investigation highlights the potential for utilizing selective coatings like Erbium Phthalocyanine to enhance the efficacy of flat-plate solar collectors through various glass cover options. While the initial results appear promising regarding improved energy capture, further experimental work is warranted.

This should include controlled measurements of water temperature under standardized solar illumination conditions, varied ambient temperatures, and wind influences. Additionally, a comprehensive analysis of the system's efficiency and heat loss dynamics is essential.

Future development efforts should focus on optimizing the ErPc deposition process to produce more homogeneous films, accurately characterizing the radiation properties of the ErPc coating, and assessing its impact on thermal performance across relevant wavelengths for solar heating applications.

Long-term evaluations across various climatic conditions are also crucial to understanding the technology's potential and the system's operational viability year-round.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Marvin-Omar and Diego-Hernan will conduct the development, experimentation, and article writing. Abel, and José Luis, helped with the correction of the manuscript.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, Cuate Gomez, upon reasonable request.

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Abbreviations

ErPc	Ebium phthalocyanine
FPCs	Flat plate solar collectors
FT-IR	Fourier-transform infrared spectroscopy
SEM	Scanning electron microscope

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