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Recent Material Research Advances for Photothermal Absorbers

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Abstract: One of the primary components in solar photothermal collectors is the absorber because its role is very influential on system performance. Recent research on developing solar photothermal absorbents has found materials with impressive absorption performance of more than 90%. The next challenge is to find environmentally friendly materials, simple and easy to manufacture, available in abundance, easy to recycle, easy to install, durable, and easy to maintain while maintaining high performance. In addition, the existing solar thermal collector is varied and requires selecting appropriate materials. Therefore, this study presents a brief review to make it easier for engineers to choose the most suitable material for solar thermal application, which is designed based on the latest research findings. Moreover, this study is also helpful for researchers as a reference source to find novelty and state-of-the-art research on photothermal absorber materials.

Keywords: phototherapy; solar collector; solar energy; solar thermal; renewable energy; solar technology; sustainable energy

1. Introduction

Global energy demand continues to increase, and adequate renewable energy sources are needed[1–7]. Solar energy is a popular renewable-sustainable energy source, and its applications increased continuously due to its huge energy potential and eco-friendly[8–13]. Moreover, solar energy sources can be utilized in various types of applications such as refrigeration[14–16], electric generation[17–19], water pumping[20–23], cooking[24], adsorption cooling[25,26], water heater[27], and air heater[28,29]. The most common mechanism for converting solar radiation energy is photovoltaics[30–32] and photothermal[31].

The technology for utilizing solar thermal energy is commonly referred to as solar thermal by utilizing the phenomenon of photothermal. The absorber is one of the main components in solar photothermal to make it can work optimally[33,34]. Recent studies have shown that the absorber can work very impressively with an absorbency level of more than 90%. The next challenge is not only the absorptivity level of at least 90%, but also it must be cheaper and environmentally friendly[35–37] or as a low-cost environmentally-friendly solution[35]. Furthermore, the solar thermal development must also consider the simple and easy manufacturing aspect[38,39], the material is available in abundance[40], easy to recycle[41], easy installation[42], long service life[24,43–45], easy maintenance[46] and economical[47–49]. These renewable technology criteria will be an effective and sustainable solution[50].

Materials with various groups have been developed and researched with the results of their unique properties. Meanwhile, the types of solar photothermal also vary with a wide range of operating conditions. For example, unconcentrated solar photothermal collectors operate at less than 100°C[51] while the concentrated types operate at over 1000°C[52]. Moreover, various types of solar photothermal are designed for various purposes such as desalination, water harvesting, sterilization, deicing, energy harvesting, wastewater treatment, oil spill cleanup, water pumping, and air conditioner[53–55]. Currently, the issue of water pollution is a severe problem in several countries[56–58]. Therefore, solar photothermal absorbers must be able to work in their respective operating conditions. Finally, it raises the challenge of selecting the suitable material to operate for a long time with a high-efficiency performance.

Responding to the problem above, this study presents various developments of the latest research innovations in material studies for solar photothermal absorbers. Furthermore, the review will provide a proper reference for engineers selecting the material for developing their solar thermal design. Moreover, our study also provides insights for researchers to discover novelty and state-of-the-art in the studies of materials engineering for solar photothermal.

2. Work Mechanism

Solar energy can be utilized and converted into various forms of energy, including electricity by photovoltaic, chemical (fuel) by photochemical, photocatalyst, and photobiochemical, health therapy by phototherapy and thermal energy by photothermal[59]. Among these technologies, the current research findings show that the photothermal conversion process is the most efficient[60]. Materials that function to absorb light and convert it into heat energy are called photothermal absorbers. Photothermal is produced by photoexcitation from absorbed light, resulting in the partial or nearly complete production of thermal energy and diffuse the heat to the external environment[61–63]. In designing high-performance solar collectors, the sunlight irradiation absorption and the efficiency of converting solar radiation energy to heat energy are the parameters that contribute most to the overall photothermal efficiency and achievable temperature[64,65].

Solar radiation in the energy conversion process of the photothermal absorber material has three interaction mechanisms: local plasmon heating, semiconductor non-radiative dilation, and molecular thermal oscillation[59,60,66]. The plasmonic mechanism is the most dominant conversion of solar energy into heat. Energy conversion occurs when a semiconductor is irradiated causing electrons to be excited in the semiconductor to produce energy near the band gap. Furthermore, the energy released from phonons results in local heating[67].

3. Performance

There are four most tested photothermal absorber material performances, namely absorbance (α) emittance (ε), efficiency (η), and temperature (T).

3.1 Absorbance

Absorbance is an optical property that represents the ability of a material to absorb received light. It is formulated by the Beer-Lambert-Bouguer law in equation (1).

$$\alpha = \log_{10} \frac{I_0}{I} \qquad (1)$$

Where I_0 is the intensity of light that is shot at the specimen (incident light) and I is the intensity of light that passes through the specimen (transmitted light). The absorbance test value is $0 - \infty$, where 0 means the material does not absorb light at all and ∞ means the material absorbs it completely. An illustration of testing equation (1) is presented in **Fig. 1**.

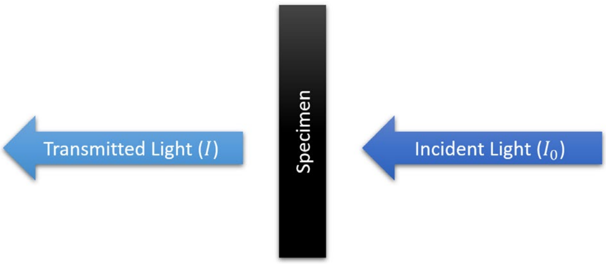

Fig. 1: Illustration of absorbance test using spectrophotometry

The absorbance performance expressed in % units is formulated in equation (2). An absorbance value of 0% means the material does not absorb light at all and 100% means it absorbs light completely.

$$10^{-\alpha} = \frac{I_0}{I} \tag{2}$$

Meanwhile, to measure absorbance at a certain wavelength range, it is formulated in equation (3)$^{68)}$.

$$\alpha(\theta) = \frac{\int_{\lambda_{min}}^{\lambda_{max}} [1 - R(\theta,\lambda) - \tau(\theta,\lambda)]\, P(\theta,\lambda) d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} P(\theta,\lambda) d\lambda} \tag{3}$$

Where λ is the wavelength of light, θ is the angle of light, R is reflectance, τ is transmittance, and P is radiation power.

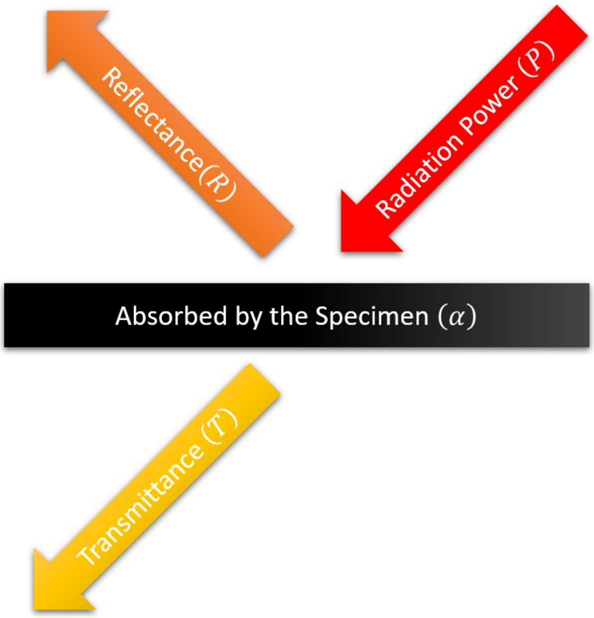

Fig. 2: Relationship between light interaction on the specimen (absorbance, reflectance, and transmittance)

With the law of conservation of energy, the illustration in **Fig. 2** can be formulated in equation (4)$^{69)}$.

$$\%\alpha + \%R + \%T = 1 \tag{4}$$

Therefore, the photothermal absorber has better performance the higher absorbance. Meanwhile, the reflectance and transmittance get better at a lower value.

3.2 Emittance

Emittance (ε) is the performance of a material which represents the ratio of the radiation emitted by a material at the same temperature to the radiation emitted by a perfectly black material$^{70)}$. The emittance performance is formulated in equation (5) with an illustration of the difference between emittance and reflectance presented in the figure.

$$\varepsilon = \frac{\int_{\lambda_{min}}^{\lambda_{max}} [1 - R(\lambda)]\, B(\lambda,T) d\lambda}{\int_{\lambda_{min}}^{\lambda_{max}} B(\lambda,T) d\lambda} \tag{5}$$

Where λ is a certain radiation wavelength, T is a certain temperature, R is reflectance, and B is black body emissive power$^{71)}$.

Photothermal absorber material is considered to have good performance if the emittance is lower $^{72)}$. A lower emittance value indicates that the material releases less heat in the form of radiation losses. In contrast to reflectance and transmittance where the losses are in the form of light radiation, emittance releases energy losses in the form of heat which is illustrated in **Fig. 3**. To reduce emittance losses, one of the efforts that can be made is by coating using low emitter material. He et al$^{73)}$ used AlCrWTaNbTi nanoceramic to coat a stainless-steel substrate to obtain a material with low emittance properties.

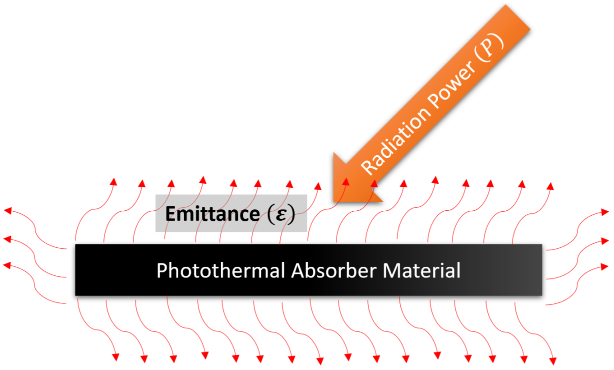

Fig. 3: Emittance illustration

3.3 Temperature

Temperature (T) measurements can generally be carried out using thermocouple sensors, laser thermometers, and camera terameters. The thing that needs to be paid attention to when using a sensor thermocouple thermometer is that the sensor is not exposed to incident light because the sensor can cause a photothermal effect. As a result, the sensor does not measure the temperature of the specimen but instead measures itself. Therefore, the solution is that the sensor should be immersed in the specimen or placed on the opposite side of the surface exposed to direct light as shown in **Fig. 4**.

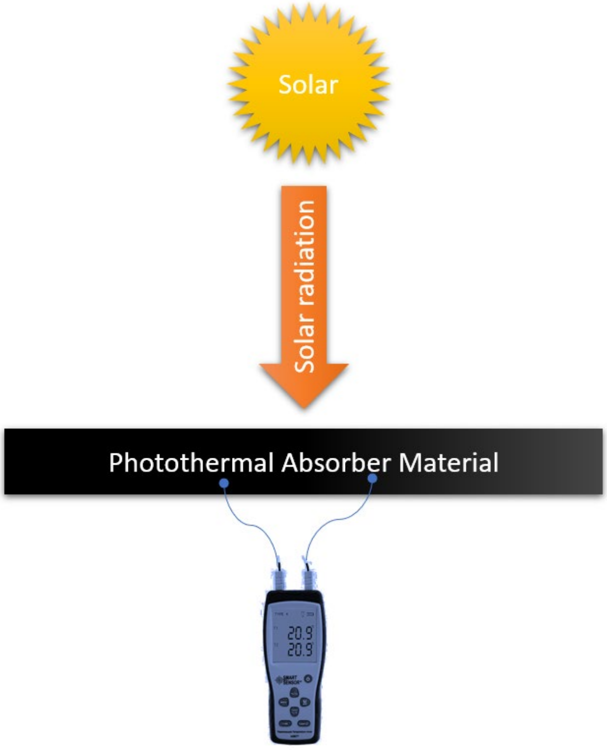

Fig. 4: Temperature measurement using thermocouple sensors

Temperature measurements using an infrared laser thermometer (gun) and thermometer camera must contain no solid material that obstructs imaging even though the material is transparent. An illustration of testing photothermal absorber material using a laser thermometer and thermal camera is presented in **Fig. 5**. Thermometers and thermal cameras only measure solid materials the first time they are exposed and they cannot measure the temperature on the backside. Camera thermal thermometers have the advantage of displaying temperature distribution, whereas thermocouple sensors and laser thermometers can only measure at certain points.

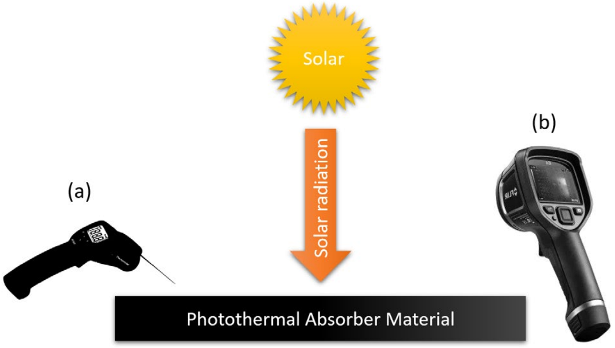

Fig. 5: Temperature measurement uses (a) laser thermometer and (b) thermal camera

In testing the temperature performance of photothermal absorber materials which can be carried out simultaneously, it can be carried out in uncontrolled environmental test conditions such as testing directly under sunlight. Meanwhile, tests carried out partially or alternately must be carried out under controlled environmental conditions. The main parameters that must be controlled are ambient temperature and light radiation sources with as small a deviation as possible. If these parameters cannot be controlled, the test data results will be unreliable.

3.4 Efficiency

The energy conversion efficiency ($\eta_{ece.abs}$) in photothermal absorbents is formulated[74,75)] in equation (6).

$$\eta_{ece.abs} = \frac{Q}{E} = \frac{m \times \Delta H_T}{I \times A_{abs} \times (\Delta t_T)} \qquad (6)$$

Where Q is the thermal energy, E is incident light during the irradiation time, m is the mass of the absorbent, ΔH_T is the enthalpy change of the absorbent at (T), I is the intensity of light illumination, A_{abs} the surface area of the absorbent exposed to radiation, and Δt_T is the time required to reach (T).

Measurements by Yan and Li,[74)] were in direct radiation conditions, whereas experiments for focused light require a light radiation focusing factor (F) which is formulated in equation (7).

$$\eta_{abs} = \frac{m \times \Delta H_T}{F \times I \times A_{abs} \times (\Delta t_T)} \qquad (7)$$

The F value comes from a combination of material transmittance ($\%T$) and concentration ratio (C), formulated in equation (8).

$$F = \%\tau_{total} \times C \qquad (8)$$

The optical concentration ratio factor (C) is the ratio of the lens surface area (A_{lens}) to the absorbing surface area (A_{abs}), formulated in equation (9)[76)].

$$C = \frac{A_{lens}}{A_{abs}} \qquad (9)$$

Light passing through the lens cannot be transmitted completely. Therefore, the transmittance of the system is a combination of the transmittance of several lenses through which light passes, formulated in equation (10).

$$\%\tau_{total} = \%\tau_1 \times ... \times \%\tau_n \qquad (10)$$

Equations (6) to (10) are simplified to obtain equation (11).

$$\eta_{energy.abs} = \frac{m \times \Delta H_{(t,m,T)}}{\%T_{total} \times A_{lens} \times I \times (\Delta t_T)} \qquad (11)$$

The vapor generation efficiency (evaporation) or solar to vapor efficiency, is formulated in equation (12)[77)].

$$\eta_{vapr} = \frac{\dot{m} \times h_v}{C \times P} \qquad (11)$$

Where $\dot{m}^{\cdot}$ is the evaporation mass flow rate and h_v is the evaporation enthalpy. Meanwhile, C is the optical concentration factor and P is solar power.

4. Material Classification

The types of materials for solar photothermal absorbers are classified into six types, namely: metal, ceramic, carbon, polymer, natural, and composite as shown in **Fig. 6**. The classification is based on the similarity of material properties and fabrication methods. Furthermore, in this material category it is further explained regarding its application, structure, manufacturing method, performance. The performance presented is in the form of light absorptiveness, light emissivity, efficiency of conversion of radiant energy to heat or vapor generation, and maximum tested temperature.

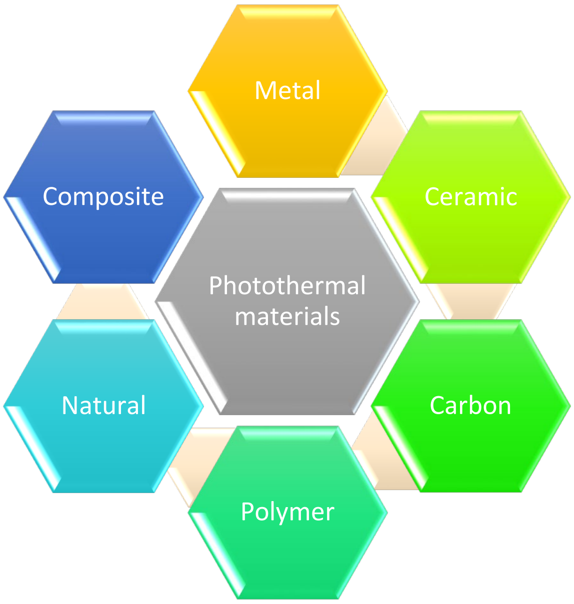

Fig. 6: Classification of solar photothermal absorber materials

4.1 Metal

Li and Wang (2020) classify metal-based materials for solar photothermal into three: plasmonic metal nanomaterials, porous metal, and metal element composites78). Plasmonic metal nanomaterials work through absorbed light energy causing electrons to be excited to produce energy near the band gap, which in turn releases energy back employing photon re-emission (luminescence) or phonon generation (heat)67,79). Besides being useful as a photothermal absorber, nanofluid material is also helpful in increasing heat capacity, conductivity of working fluids, and dynamic viscosity80–82). While the porous metal material works by trapping the light that enters the pores83). The metal element composite works by combining different material properties to obtain new material properties, which are discussed further in the composite materials chapter.

In general, metal materials have excellent properties because they have high thermal stability51,73,84–88). Moreover, metal is the primary commodity in solar energy applications89). With various structures, metallic materials can operate with more than 95% absorptivity78,90,91). Therefore, metal materials are suitable for concentrated solar photothermal absorbers. However, metal material is more expensive when compared to carbon-based materials and is prone to corrosion78).

Generally, virgin metal materials have high reflectivity; consequently, their absorptivity is low. Metals require manufacturing engineering with a selective coating method to have a high absorptivity92). Therefore, the metal material in the solar collector functions as a substrate absorber coated by a selective absorber with high absorbance values, low emissivity, and low reflectivity. If desired without coating, the reflectivity of metallic materials can be reduced, and the absorbance of light can be increased by forming a narrow cavity structure such as foam or sponge. The most commonly used metal materials for solar photothermal absorbers are titanium93,94), aluminum95–97), copper98–102), and stainless steel45,93,103). Generally, a single metal material (non-composite) for plasmonic models use nanoparticle structure, **Fig. 7**. (a), or film, **Fig. 7**. (b), that simultaneously acts as a nanofluid78). The thin film is more promising for vapor generation, while the nanofluid is more promising for temperature generation and heat transfer. Vapor generation will have the property of inhibiting temperature generation because the evaporative cooling effect occurs with the release of heat through the vapor medium104,105).

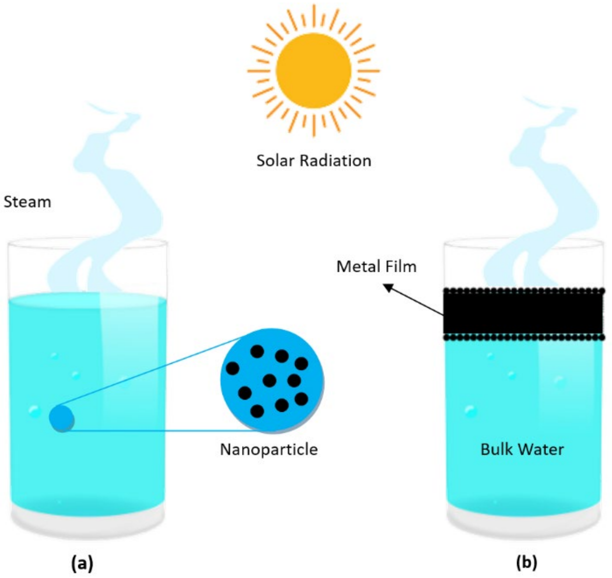

Fig. 7: Two types of plasmonic models for steam generation application (a) nanoparticle and (b) metal film (source: author's document)

Table 1. Recent findings of metal materials as photothermal absorbers.

Types	Application	Structure / Manufacturing Method	Performance				Ref.
			α	ε	η	T	
Titanium	Photothermal in general	Ultrathin Titanium / Aluminum Nitride / Titanium parallel coating on a stainless-steel substrate	89%	19%	Na	Na	93)
	Solar thermal steam generation, desalination, macula-removing, and biological sterilization	Titanium spheres in the hydrogel layer	93.6% (average) 98.9% (maximum)	Na	>90%	Na	94)
Aluminum	Concentrated power solar absorber	Composite ceramic films on aluminum substrate	95.20%	5.45%	Na	>400°C	95)
	Photothermal in general	Nanoporous anodic aluminum oxide (NPAAO) films on 6061-T6 aluminum alloy	Na	<7.7% (reflectance)	Na	290 °C	96)
	Photothermal and radiative cooling	a 200-nm-thick metallic aluminum (Al) film + aluminum oxide (Al_2O_3) wafer	>80%	Na	Na	185°C (heating) −12°C (cooling) 20°C (ambient)	97)
Copper	Solar steam generation	Copper sulfide-macroporous polyacrylamide hydrogel	>80%	Na	92%	55.3 °C	98)
	Solar thermal energy storage and photothermal conversion	Microencapsulated phase change materials with copper and copper oxide	Na	Na	62.79%	245 °C	99)
	Solar thermal in general	CuO in selective dip-coating on Cu substrat	75.02%	75.02%	46.38%	Na	106)
	Photocatalysis, solar energy harvesting, optoelectronics, and biomedical technologies	Cu-Based Core−Shell Nanoparticles	Na	Na	66%	Na	100)
	Solar thermal parabolic trough collecto	Volumetric porous foam	Na	Na	60%	12.2 °C (enhancement from ambient)	102)
Stainless steel 45,93,103)	High temperature solar thermal collector	Textured stainless steel coated with AlCr oxide	86%–92%	Na	Na	800 °C	45)
	Photothermal in general	Ultrathin Titanium / Aluminum Nitride / Titanium parallel coating on a stainless-steel substrate	89%	19%	Na	Na	93)
	Solar thermal heat harvesting	Dielectric/conducting multilayer coating on Stainless Steel tubes	~85%	0.14%	Na	350 °C	103)

*Notes: α = absorbance, ε = emittance, η = efficiency, and T = temperature.

4.2 Ceramic

Ceramic materials are the choice to manufacture photothermal absorbers that are safe against damage at high temperatures while maintaining high spectral selectivity, conductivity and radiation properties at working temperatures107). The most striking advantage of ceramics is their chemical structural and corrosion resistance108,109). Therefore, ceramic materials are very suitable for concentrating solar photothermal. However, ceramic materials are more expensive, difficult to fabricate, and difficult to recycle than metals. Therefore, the dark ceramic material is more suitable for application as a selective absorbent coating material than as a substrate absorbent material for solar collectors.

The type of ceramics that have been widely studied for thermal absorbers include barium titanate $(BaTiO_3)$110–112), silicon carbide (SiC)113–116), silicon nitride (Si_3N_4)117,118), aluminum oxide (Al_2O_3)96,119–122), and titanium carbide (TiC)123–125). Data on the latest developments in ceramic materials as photothermal absorbers with application details, structure, manufacturing methods and performance are presented in the Table 2.

The data shows that the temperature performance of the ceramic-type material as a photothermal absorber work with a very wide susceptibility, starting from low temperatures of less than 100°C to more than 1000°C. The temperature achieved by the ceramic material in converting light radiation energy into heat is affected by the intensity of the light received. A concentrated collector lens or mirror is the most common method used to increase the intensity of light a material receives.

Table 2. Recent findings of ceramic materials as photothermal absorbers.

Types	Application	Structure / Manufacturing Method	Performance				Ref.
			α	ε	η	T	
Barium Titanate ($BaTiO_3$)	Conversion of CO_2 to methane (photothermal-photocatalyst)	Composite with nickel nanoparticle	Na	Na	94.4% conversion	270 °C	110)
	Seawater desalination	Composite with carbonized sawdust	Na	Na	72.04%	Na	111)
	Light-to-heat conversion	Nanoparticles	Na	Na	Na	55.5 °C	112)
Silicon Carbide (SiC)	Radiative cooling and light absorption	Coatings	91.24%	8%	Na	Na	113)
	Solar heat harvesting	Hybrid nanofluid with indium-tin-oxide (ITO)	98.9%	Na	34.1%	Na	114)
	Heat harvesting	Microcapsule containing phase change materials (microPCMs) with melamine urea formaldehyde (MUF)	>90%	Na	74.4%	61.1 °C	115)
	Heat harvesting	Foam	Na	Na	85.4%	> 1000 °C	116)
Silicon Nitride (Si_3N_4)	Heat harvesting in concentration solar power (CSP)	Layers coating (Inconel / $MoSi_2$ $-4Si_3N_4$ / Si_3N_4 / Al_2O_3)	92 ± 0.5%	33 ± 0.5	Na	700 °C	117)
	Heat harvesting in concentration solar power (CSP)	Layers coating (TiB_2 / TiB(N) / Si_3N_4)	96.4%	18%	Na	82 °C	118)
Aluminum Oxide (Al_2O_3)	Heat harvesting and photothermal sensor	Layers coating	Na	Na	Na	290 °C	96)
	Heat harvesting	Photonic crystal coatings	90%	11%	Na	Room temperature	119)
	Direct absorption solar thermal collector	Blended nanoparticle (Al_2O_3/Co_3O_4)	> 80%	Na	Na	increase 19.4 °C form ambient temperature	120)
	Hear harvesting using solar thermal	laminated cubic solar absorber (LCSA) by metal-dielectric bilayers	>90% at 420–2112 nm and >96.32% 280 nm–2500 nm	Na	90%	1726.85 °C	121)
	CO_2 hydrogeneration	Membrane	Na	Na	Na	329 °C	122)
Titanium Carbide (TiC)[123–127)]	Heat energy harvesting in high temperature	One-layer nano-composite TiN/TiC-based cermet coatings	≈80.1%	≈2%	Na	650 °C	123)
	Solar heat energy harvesting	TiC–SiC composites	Na	Na	Na	500 – 1000 °C	124)
	Bulk solar absorber	SiC-TiC nanocomposite	76%	44%	Na	1550 °C	125)
Copper Oxide (CuO)	General application (unspecified)	Thin films are made by spray pyrolysis	85% to 92%	Na	Na	400 °C	128)
	Solar selective absorber in general	Thin films coating of reduced graphene oxide wrapped copper oxide (rGO-CuO)	825	5%	Na	Na	129)
	solar thermal energy harvesting	Copper oxide (CuO) nano coatings on stainless steel (SS) substrate	97.4%	40.8%	Na	Na	130)

*Notes: α = absorbance, ε = emittance, η = efficiency, and T = temperature.

4.3 Carbon

Carbon-based materials have many excellent properties for solar photothermal absorbers[131)]. Naturally, the carbon material is black, so it promises high absorbance. However, carbon materials do not necessarily absorb all light because there is still a Fresnel reflection at the dielectric interface of 5-10%[132)]. The main challenge of the nature of carbon materials is hydrophobic because it weakens the heat exchange between water and material[87,131,133,134)]. Combining hydrophobic and hydrophilic materials is the solution to increasing the contact between the adsorbent and water so that the heat transfer increases.[135)]. In a system, there are three heat transfer mechanisms, namely radiation, conduction and convection[136)]. In addition, experimental results on a flat plate solar collector show that carbon material in nanofluid particles as a heat transfer fluid is unstable[137)]. Therefore, additional treatment is still needed to improve the performance of the heat transfer fluid, such as by combining it with other materials, including coating, mixing, encapsulation, and other methods. Increasing heat transfer can also be done by making the perforated fins structure[138)].

The type of carbon materials that are widely used as solar thermal absorbers include mesoporous carbon[41,139–141)], carbon dots[142–146)], carbon nanofluid[147–152)], graphene/graphite[153–159)], fullerene[160–162)], and carbon nanotube (CNT)[163–167)]. Application, structure, manufacturing method and performance of each type of carbon material as a photothermal absorber are presented in Table 3.

Amorphous carbon is better for low thermal propagation applications because it has a lower thermal conductivity than crystalline carbon[168,169)]. Material conductivity properties consideration is important because materials with high thermal conductivity prevent heat concentration which reduces the local thermal effect[170)]. Therefore, several methods to reduce thermal conductivity have been proposed, such as preparing porous materials in which the air entering the pores has high thermal resistance to suppress thermal dissipation.

Carbon is widely used as a photothermal absorber material because, abundantly available, the absorptivity performance is more than 90%, easy to manufacture, and the light absorptivity range is quite comprehensive (200-800nm)[171)]. Moreover, various carbon materials can be combined to obtain multiple structures. Table 3 shows that various carbon materials can be formed with numerous systems structures and used in multiple applications with different performances. Carbon material at the nanoscale not only functions as a photothermal absorber but is also helpful in improving the properties of heat transport media[172)] and has the potential for commercial scale development[173)]. Moreover, the use of nanoparticle fluid material can improve the superior thermal and optical properties of solar collectors[174)]. Other studies also argue that a decrease in the price of graphene carbon material will increase the use of this type of material in a broader range of solar collectors' applications[175)].

Table 3. Recent findings of carbon materials as photothermal absorbers.

Types	Application	Structure / Manufacturing Method	Performance			Ref.
			α	η	T	
Mesoporous carbon [41,139–141)]	Solar steam generation	Geopolymer–Mesoporous Carbon Composites	≈89%	>84.95%	82.1 °C	41)
	Heat harvesting by direct absorption solar collectors	Partial substitution of dual plasmonic Au–Ag alloy nanoparticles.	91.7%	71.1%	57.1 °C	139)
	Vapor generation	Laser-induced graphene composite material (LMPC)	89–99%	98.7% thermal-vapor conversion rate	76 °C (absorber surface) 75 °C (water body)	140)
		Monolithic biomass porous carbon (MPC)	85–95%	88% thermal-vapor conversion rate		
	Heat energy harvesting	Layer composite with gradient index glass	>40%	Na	>50 °C	141)
Carbon dots	Water purification	composite (carbon dots-wood) (Nanoparticle-aggregate)	Na	93.9% (solar to steam)	Na	142)
	Water evaporation	Dual layer composite (carbon dots-wood) (nanoparticle-microchannels)	Na	92.5% (solar to steam)	44 °C (at absorber) 31 °C (at bulk water)	143)
	Photothermal – phototherapy (cancer therapy)	bioinspired sulfur-doped carbon dots	Na	55.4%	Na	144)

	Solar photothermal (PT) - thermoelectric generator (TEG)	Layer composite	Na	~46.6%	114°C	145)
	Seawater desalination	Phosphorus doping into carbon nanostructures	Na	83.6%	89.5°C	146)
Carbon nanofluid	Direct absorption parabolic solar collector	Nanofluid	94%	73.41%	43.49 °C	147)
	Water desalination	Nanoparticles 50 nm	Na	Improve 36 %	80–100 °C	148)
	Heat energy harvesting in a compound parabolic concentrator	Nanoparticle	Na	55.88%	35 °C (increase 10°C than ambient temperature).	149)
	Heat energy harvesting in a tubular direct absorption solar collector	Nanoparticle	Na	80%	Increase >29.3 °C from ambient	150)
	Solar heat energy harvesting and water heating in a continuous flow system	Carbon quantum dots nanofluid	Na	Na	>60 -144.5 °C (surface area)	151)
	Direct solar absorption	Nanoparticle 200 nm	87%	Increase 200% than base fluid	85 °C	152)
Graphene/graphite	Water heating and/or steam generation for domestic water heating and solar-driven desalination	Plasmonic graphene polyurethane nanocomposites	Na	96.5%	84.2 °C	153)
	Photothermal in general	Nitrogen-doped graphene	Na	87%	Na	126)
	Solar heating or distillation	Thin films microstructure	97.4%	84.6%	Na	154)
	Steam generation	Integrated structure of graphite powder (GP) and a semipermeable collodion membrane (SCM)	Na	56.8%	34.9 - 35.2 °C (top water surface)	155)
	Steam generation	Hybrid of graphene oxide and carbon black	Na	~98%	~ 58 °C (surface area)	156)
	Steam generation	Membrane with random layers	97%	90% -92% (directly proportional to the increase in light concentration 1-5)	43 °C (steam) ≈40 °C (membrane)	157)
	Thermal energy harvesting by direct absorption	Nanoparticles in volumetric	Na	77%	43 °C	158)
	Heat transfer fluid for closed-loop solar thermal collector	Nanoplatelets nanofluids	Na	90.7%	23.6 °C	159)
Fullerene	Photothermal therapy and photodynamic therapy	Nanoparticles	Na	99.82% (drug-loading efficiency)	68 °C (tumor site)	160)
	Heat harvesting in low-temperature solar collector	Nanoparticles Fluid	Na	<70% or increase 47.2% compare to pure water	Na	161)
	Photothermal therapy	Nanovesicles	94%	52.3%	Na	162)

Carbon nanotube (CNT)	Solar steam generation and wastewater purification	Diatomite/carbon nanotube combined aerogel	Na	91%	Na	163)
	Solar steam generation	Porous organic Semiconductors layers (covalent triazine framework (CTF)- carbon nanotube (CNT))	Na	93.2%	~72 °C	164)
	General solar energy harvesting	Nanocomposite films coating (VO_2–CNT)	Na	Na	25-95 °C (surface)	165)
	Solar evaporator	Porous Ni/CNTs composite membrane	94.3%	Na	58.9 °C	166)
	Cleanup of crude oil spills	micro spherical aerogels based on carbon nanotubes/reduced graphene oxide (CNT/RGO)	> 90%	Na	91 °C	167)

*Notes: α = absorbance, ε = emittance, η = efficiency, and T = temperature.

4.4 Polymer

Optically active nano polymers are one of the promising photothermal absorber materials for low to middle-temperature solar collectors because of their high light absorbance performance, affordable cost, lightweight, and easy chemical manipulation[132]. However, polymeric materials are unsuitable for operation at high temperatures due to their low thermal stability[176]. Therefore, polymeric materials for photothermal absorber are more suitable for low temperature applications such as phototherapy[177]. Recently, photothermal for cancer therapy has gotten much consideration because of its non-invasive nature, good temporal-spatial assurance, and minor drug resistance[178].

In general, polymeric materials that promise as photothermal therapy absorbers are conjugated polymers (CPs) which are a type of organic semiconductor material with large π-conjugated performance and have a delocalized electronic structure[179]. Moreover, polymeric materials are also suitable for use in solar collectors with low-temperature performance of less than 100°C. Polyaniline (PANI)[180–186], Polythiophene (PTh)[187–189], Polydopamine (PDA)[190–195], and Polypyrrole (PPy) [180,196–204] based materials are a popular type of CPs investigated recently as substantial electron delocalization structures because they have optical properties that are feasible as photothermal absorbers[205]. The summary of polymer materials as photothermal absorbers based on application, structure/manufacturing method and performance is presented in Table 4.

Table 4. Recent findings of polymer materials as photothermal absorbers.

Types	Application	Structure / Manufacturing Method	Performance			Ref.
			α	η	T	
Polyaniline (PANI)[177,180–186]	Potential clinical applications	Polypyrrole and polyaniline nanocomposites	≈ 60%	≈ 24%	≈ 80 ℃	180)
	Photothermal conversion and electricity generation	Polyaniline (PANI) nanoparticles into porous Anodic Aluminum Oxide (AAO) membrane	Variative	Na	> 60 °C	181)
	Solar steam generation	Three-dimensional self-floating foam composite impregnated with porous carbon and polyaniline	96.1%	87.3%	48.6 °C	182)
	Wearable electronics and smart garments	Multi-responsive fabric composite	Na	Na	57.8 °C	183)
	Photoacoustic Imaging-Guided Anticancer Phototherapy	Nanoparticles (Gold Nanostar@Polyaniline)	Na	78.6%	≈ 60 ℃	184)
	Tumor therapy	Polyaniline-grafted nanodiamonds	Variative	Na	44.4 °C	185)
	Solar evaporation	Bioinspired polyaniline composite polyurethane sponge	Na	80%	86.1 °C	186)
Polythiophene (PTh)	Photothermal therapy in cancer treatment	Nanoparticles	Na	Na	49.4 °C	187)

	Killing multidrug-resistant bacteria	Nanoparticles	Na	Na	37 °C	188)
	In vivo dual-modal imaging guided synergistic photothermal/radiation therapy	MoS_2 Quantum Dot@Polyaniline Inorganic–Organic Nanohybrids	Variative	Na	37 °C	189)
Polydopamine (PDA)	Boosting solar steam generation	Polydopamine/wood composites	87%	≈ 77%	≈ 40 °C	190)
	Tunable photothermal actuator	Polydopamine nanoparticles in hydrogel bilayers	Variative	Na	Na	191)
	Plasmonic photothermal cancer therapy	Polydopamine coated gold nano blackbodies	Variative	Na	> 50 °C	192)
	Photothermal therapy for liver cancer knocks down the anti-cancer target NEDD8-E3 ligase ROC1 (RBX1)	Nanoparticles	Variative	78.3 ± 4.6%	48 °C	193)
	Potential for photothermal treatment	Polydopamine sub-microspheres	Na	Na	> 48 °C	194)
	Photothermal/chemodynamic cancer combination therapy	Polydopamine nanoparticles coated with a metal-polyphenol network	≈83.4 %	22.7 %	37 °C	195)
Polypyrrole (PPy)	Solar generators for desalination	Ag/polypyrrole co-modified poly(ionic liquid)s hydrogels	96%	88.7%	42.9 °C	196)
	Photothermal conversion and thermosensing functions for wearable applications	Integrated polypyrrole-based smart clothing	Variative	Na	68.4 °C	197)
	Photothermal-assisted photoelectrochemical water oxidation	Polypyrrole modification on $BiVO_4$	~60%	63%	44.6 °C	198)
	Photothermal energy storage	Polypyrrole-coated expanded graphite-based phase change materials	Variative	Na	120 °C	199)
	Oil/water separation	Superhydrophobic cotton via polypyrrole deposition	Na	91.8%	59.5 °C	200)
	Solar desalination	Photothermal converting Polypyrrole/Polyurethane composite foams	Na	86.9%	61.2 °C at 4-sun	201)
	Precise raman/photoacoustic imaging and photothermal therapy	Hybrid Polypyrrole and Polydopamine nanosheets	Variative	69%	37°C	202)
	Water extraction	Polypyrrole-modified cotton fabric with tunable microstructures	>98.3%	Na	48.3 °C	204)
	Photothermal energy conversion and storage	Flexible textiles with polypyrrole deposited phase change microcapsules	Na	93.14%	75.6 °C	203)

*Notes: α = absorbance, ε = emittance, η = efficiency, and T = temperature.

PANI is one of the conductive polymers and currently popularly researched[206]. It has the advantage of being easy to produce quickly using many methods of engineering oxidation numbers to obtain different colors[207]. Moreover, PANI is popular in applications in the biomedical field because it has high conductivity, reliable biocompatibility, stable photostability, and the capability of light-to-heat conversion due to its reversible control capabilities through protonation doping and redox[208]. Therefore, PANI is a superior photothermal material because of its high light absorption performance in visible and near-infrared (NIR) light waves for energy conversion into heat and also has low light reflection loss properties[209,210]. Apart from being a photothermal therapy, the PANI material performs well as a basic material for composite sponges in seawater desalination applications[186].

PTh-type polymers have excellent photostability, high light harvesting performance, simple manufacturing, and diverse applications with various combinations of substituents[208]. In NIR light irradiation, polythiophene shows the ability of photothermal and photodynamic effects so that this material has the potential as an antigen. Bhattarai and Kim (2020) found a hyperthermal effect on the PTh nanoparticle synthesized from Surfactant-Free Oxidative Polymerization, which was tested on Colorectal Carcinoma Cells[187]. The PTh antigen effect under NIR radiation also has been presented by Li et al. (2022) where they synthesized the enhanced PTh/MnO2@M nanovaccine during tumor and cancer immunotherapy[211].

PDA is a conjugated polymer that has been extensively studied with various structures, combinations, and applications. The most common application is as a photothermal therapy for cancer. This material works with the mechanism of cancer hyperthermia therapy which can be combined with chemotherapy, photothermal, or photodynamic therapies to obtain optimal efficacy[212]. Khurana et al. (2022) developed a nano-sized black gold-coated PDA to overcome spatial thermal damage during the photothermal therapy process[192]. Wang et al. (2022) used a PDA of semi-micro particle size supported by Palladium nanoparticles to accelerate the reaction of a thermal catalyst under visible light and NIR radiation testing[213]. Wujie et al. (2022) innovated with Cu 2-x Se@PDA nanoparticle and found that the material killed >95% of MCF-7 cells in NIR irradiation with a wavelength of 808 nm for 5 minutes[214]. Aside from being a photothermal therapy material, PDA has also been studied as a steam generator. Zou et al. (2021) developed a polydopamine/wood composite with a vapor generation efficiency performance of ≈77% under 1 sun illumination[190]. The next application of PADA material is as an actuator, where Lee et al. (2022) developed a controllable bilayer actuator incorporated with PDA nanoparticles[191].

Another high-performance conductive polymer, i.e., black PPy and its derivatives due to better photothermal stability compared to PANI[132], and the biocompatibility is also excellent[215–220]. In addition, its low light reflectance, wide operating wavelength range (200-2500 nm) as well as high photo-to-thermal conversion efficiency of more than 90%[221–227]. Moreover, PPys is easily coated with various substrates such as conductive and non-conductive materials with curved structures[228].

Poly(N-phenylglycine) or (PNPG) is the next polymer class material often used in photothermal processes. PNPG material with a water lily structure can be used for steam generators with a higher efficiency performance of 93.5%[229]. In addition to working with photothermal, PNPG can be combined with other light energy conversion methods and produce double application combinations. PNPG with a layer structure combined with MoS_2 Nanohybrid using a Photothermal-Photoelectric method can generate steam and electricity simultaneously[230]. Moreover, PNPG is also helpful as a tanker therapy or commonly referred to as photothermal-phototherapy, using a spectrum of Near Infrared light (NIR)[231].

4.5 Natural

Natural materials are classified based on their properties obtained directly from nature without any processing which results in damage to their natural properties. The crushing treatment, but the material does not become too small, is still categorized as a natural material because it does not change the natural properties. Natural materials are believed to have the advantage of being biodegradable, having a low impact on the environment, being abundantly available, affordable and sustainable[232,233].

In general, natural materials have lower performance than metamaterials because they only rely on their natural properties. However, the material's properties as solar photothermal can still be utilized. Natural materials that previous researchers as solar thermal absorbers, have studied include asphalt[234–238], sand[239–241], gravel[36,242,243], stone[244,245], pumice[245,246], and pebble[247,248]. Aside from being a solar photothermal absorber, natural materials such as crushed gravel sand can be used as heat storage and increase the vapor temperature in the preheating process, increasing the vapor production speed[249]. The summary of natural materials as photothermal absorbers based on application, structure/manufacturing method and performance is presented in Table 5

Table 5. Recent findings of natural materials as photothermal absorbers.

Types	Application	Structure / Manufacturing Method	Performance			Ref.
			α	η	T	
Asphalt	Solar collector	Self-healing asphalt mixture with fibres	Na	Na	53 °C	235)
	Solar energy harvesting, conversion, and storage	Phase change materials (PCMs) composites (polypyrrole and asphalt)	Na	93.8%	> 90 °C	236)
	Road anti-icing and de-icing	Superhydrophobic emulsified asphalt coating modified by CNTs and PTFE	Na	Na	42.8 °C	237)
	Anti-icing	Superhydrophobic coatings on	Na	Na	increase of	238)

		asphalt pavement			9.2 °C	
Sand	Solar evaporator for large-scale and scalable freshwater production	Sandy sediment	90 %	97 %	56.4 °C	239)
	Solar-to-thermal purified water harvesting	Black sand aggregate	98.25%	82.63% under 1.5 sun	43.4 °C	240)
	Wastewater purification	Quartz sand@g-C_3H_4/CoFe-LDH core/shell heterostructures	Na	95.35 %	57 °C	241)
Gravel	Solar air heating system	Granular	> 92%	10% (exergy efficiency)	> 60 °C	36)
	Energy storage materials for performance improvement of hemispherical distillers	Black gravel	Na	56%	69 °C	242)
	Sensible heat storage material	Natural gravel	Na	53.3%	102 °C	243)
Stone	Porous sensible absorber of solar still	Basalt stones	Na	22.6%	63.7 °C	244)
	General photothermal absorber	Andesite granular natural stone	Variative	Na	89.00 °C	245)
Pumice	General photothermal absorber	Pumice granular natural stone	Variative	Na	73.00 °C	245)
	Sensible heat storage of solar still	Pumice granular natural stone	Na	62.4%	≈ 73.00 °C	246)
Pebble	Sensible thermal storage materials in solar stills	Natural pebble	Na	53%	54 °C	247)
	Photothermal absorber for water heater solar thermal collector	Coated pebble	Na	47.23%	≈ 60 °C	248)

*Notes: α = absorbance, ε = emittance, η = efficiency, and T = temperature.

Due to low performance but low cost, natural materials are more suitable for low-temperature applications and suitable for large-scale applications. Therefore, natural materials in solar photothermal are more promising for space heating and building materials. In a building design, choosing energy-saving material is a critical consideration[250–252]. Ultimately, energy savings have implications for optimal economic benefits[253,254]. However, many types of natural materials have not been studied, so they still provide potential for applications at medium and high temperatures. Naturally dark or black in color and porous materials deserve further study regarding their potential as high-performance, inexpensive, and environmentally friendly photothermal absorbers.

4.6 Composite

Every single material has its advantages and disadvantages. By combining various materials, new material properties will be obtained by maintaining the structure of the constituent materials[255–258]. For example, most metallic materials have a high enough reflectivity; thus, the light absorptivity becomes low. Therefore, a selective photo absorber material is coated, which is generally made of ceramic. With this method, a composite sandwich material has been obtained. An example in this case is aluminum covered by TiN/TiNxOy/SiO2[95]. Sandwich structures in photothermal solar have been classified into intrinsic absorbers, semiconductor metal tandem absorbers, cermet absorbers, textured absorbers, DMD absorbers, multilayer absorbers, and selective solar-transmitting coatings on a blackbody-like absorber[259].

Another composite structure is the solar photothermal membrane[166,260–264]. This material is often used as vapor generation for desalination or water purification purposes[265]. The narrow slits in the membrane structure are useful for trapping the radiating light, thereby reducing its reflection. Moreover, the narrow-slit structure is also beneficial for lifting water by the capillarity effect. A composite structure that combines high water absorptivity at the bottom and high light absorption at the top will optimize the performance of the membrane structure as a solar vapor generator.

5. Concluding remarks

The photothermal absorber is one of the main components in the solar collector whose role is very influential on system performance. Recent research on developing solar photothermal absorbers has found materials with impressive absorption performance of more than 90%. The next challenge is to find environmentally friendly materials, simple and easy to manufacture, available in large quantities, easy to recycle, easy to install, durable, and easy to maintain while maintaining high performance. In addition, the existing solar thermal collectors vary and require the selection of appropriate materials.

The results showed that there are 6 materials suitable for use as solar photothermal absorbers, namely metal, ceramic, carbon, polymer, natural, and composite. The ceramic material type has very good performance and is long-lasting so it is suitable for high-concentration and high-temperature solar collectors, but it tends to be more expensive. Therefore, the ceramic type is suitable for collectors for solar power plants. The metal type is not as expensive as the ceramic type but its performance is not as good as the ceramic type. However, metals can still be used for medium to high-temperature solar collectors. Applications of photothermal absorbers for medium to high temperatures include solar water heating on a household and industrial scale. Furthermore, the carbon type tends to be cheaper than the ceramic and metal types, but its performance is not as good as either of them. The carbon type is easily damaged at high temperatures so it is suitable for low to medium solar collectors such as generating steam in the desalination process, water treatment, and household water heating. Furthermore, the Polyaniline (PANI), Polythiophene (PTh), Polydopamine (PDA), and Polypyrrole (PPy) polymer types work at low temperatures. Its non-toxic nature has been widely developed as an agent for the treatment of cancer and cancer. This material is not commonly used in solar collectors because it is easily damaged even at medium temperatures. However, it has the potential to be applied to low-temperature collectors such as for vapor generation. Meanwhile, natural materials are the most environmentally friendly materials because they do not pollute the environment and are the cheapest because they do not need complex treatment to maintain their natural properties. There are still various natural materials whose performance as photothermal absorbers has not been studied. The materials that have been tested so far can work at low to medium temperatures so their application is similar to the carbon type. The composite class was developed to answer the challenges of the weaknesses and strengths of each material. This material was developed by combining various materials so that new, unique properties emerge according to needs. The use of composite materials is very wide from low to high temperatures. The majority of materials reported by researchers recently can be classified as composite materials.

It concluded that no material has perfect properties. Therefore, engineers must understand and choose the most appropriate material for the designed solar photothermal application. In addition, there are many opportunities for researchers to discover scientific novelties by cross-experimental or cross-modeling various kinds of existing or new structures with existing or new materials. In the future, testing solar thermal absorber materials for environmental sustainability is also essential instead of just testing the engineering performance.

Nomenclature

α = absorbance
ε = emittance
η = efficiency
T = temperature
I_0 = incident light
I = transmitted light
R = reflectance
θ = angle of light
τ =transmittance
P = radiation power
B = black body emissive power
λ = certain radiation wavelength
η = efficiency
m = mass of the absorbent
H = enthalpy
A = surface area
t = time required to reach
F = light radiation focusing factor
C = optical concentration ratio factor
$\dot{m}$ = the evaporation mass flow rate

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References

1) R.A. Jessam, “Experimental study of wind turbine power generation utilizing discharged air of air conditioner blower,” *Evergreen*, **9** (*4*) 1103–1109 (2022). doi:10.5109/6625722.
2) J. Santosa, A.H. Kuncoro, A. Dwijatmiko, N.W. Hesty, and A. Darmawan, “The role of nuclear power plants in indonesia towards net zero emissions (nze) in 2060 with a multi regions approach,” *Evergr. Jt. J. Nov. Carbon Resour. Sci.*

Green Asia Strateg., **10** (*03*) 1–14 (2023).
3) R.F. Naryanto, E. Hiroshi, M.K. Delimayanti, A.D.N.I. Musyono, and A. Naryaningsih, "Tar characteristics as influenced by air flow rate changes in a downdraft gasifier," *Evergreen*, **10** (*2*) 842–850 (2023). doi:10.5109/6792837.
4) D.M. Prabowoputra, A.R. Prabowo, I. Yaningsih, D.D.D.P. Tjahjana, F.B. Laksono, R. Adiputra, and H. Suryanto, "Effect of blade angle and number on the performance of bánki hydro-turbines: assessment using cfd and fda approaches," *Evergreen*, **10** (*1*) 519–530 (2023). doi:10.5109/6782156.
5) J. Waluyo, M.M. Setianto, N.R. Safitri, S.H. Pranolo, A.D. Susanti, Margono, and Paryanto, "Characterization of biochar briquettes from coconut shell with the effect of binder: molasses, cow manure and horse manure," *Evergreen*, **10** (*1*) 539–545 (2023). doi:10.5109/6782158.
6) B. Anggara, E.P. Budiana, C. Harsito, K. Enoki, K. Ki-Seong, I. Yaningsih, and D.D.D.P. Tjahjana, "Performance improvement of h-darrieus wind turbine with high efficiency vortex structure attachment," *Evergreen*, **10** (*1*) 496–503 (2023). doi:10.5109/6782153.
7) M. Al-Ghriybah, "Assessment of wind energy potentiality at ajloun, jordan using weibull distribution function," *Evergreen*, **9** (*1*) 10–16 (2022). doi:10.5109/4774211.
8) A. Fadhila Pachman, D. Hissein Didane, M. Al-Ghriybah, N. Fitriah Nasir, S. Al-Alimi, and B. Manshoor, "A study of global solar radiations measurement in java island, indonesia," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, **10** (*1*) 212-218 (2023). doi:10.5109/ 6781071.
9) M. Motinur Rahman, S. Saha, M. Z. H. Majumder, T. Tamrin Suki, M. Habibur Rahman, F. Akter, M. A. S. Haque, and M. Khalid Hossain, "Energy conservation of smart grid system using voltage reduction technique and its challenges," *Evergreen*, **9** (*4*) 924–938 (2022). doi:10.5109/6622879.
10) A.H. Ismail, E.A. Dawi, N. Almokdad, A. Abdelkader, and O. Salem, "Estimation and comparison of the clearness index using mathematical models - case study in the united arab emirates," *Evergreen*, **10** (*2*) 863–869 (2023). doi:10.5109/6792841.
11) B.A. Shallal, E. Gedik, H.A.A. Wahhab, and M.G. Ajel, "Impact of alumina nanoparticlesadditives onopen-flow flat collector performance for pv panel thermal control application," *Evergreen*, **10** (*2*) 870–879 (2023). doi:10.5109/6792842.
12) I. Yaningsih, D.D.D.P. Tjahjana, E.P. Budiana, M. Muqoffa, Z. Arifin, Suyitno, K. Enoki, and T. Miyazaki, "Numerical study on the effect of rectangular and triangular counter-rotating vortex generators on the h-rotor wind turbine performance," *Evergreen*, **10** (*1*) 230–241 (2023). doi:10.5109/6781073.
13) K. Marzia, M.F. Hasan, T. Miyazaki, B.B. Saha, and S. Koyama, "Key factors of solar energy progress in bangladesh until 2017," *Evergreen*, **5** (*2*) 78–85 (2018). doi:10.5109/1936220.
14) Ashwni, and A.F. Sherwani, "Assessment of the impact of using zeotropic mixture on the thermodynamic performance of organic rankine cycle integrated vapor compression refrigeration system," *Evergreen*, **10** (*2*) 1094–1099 (2023). doi:10.5109/6793668.
15) G. Sachdeva, B. Sharma, P. Anuradha, and S. Verma, "Irreversibility analysis of an ejector refrigeration cycle by modified gouy-stodola formulation," *Evergreen*, **10** (*1*) 252–271 (2023). doi:10.5109/6781075.
16) L. Yadav, A.K. Verma, V. Dabra, and A. Yadav, "Performance comparison of different desiccant material based wheels for air conditioning application," *Evergreen*, **10** (*2*) 912–923 (2023). doi:10.5109/6792886.
17) N. Kumari, S.K. Singh, and S. Kumar, "MATLAB-based simulation analysis of the partial shading at different locations on series-parallel pv array configuration," *Evergreen*, **9** (*4*) 1126–1139 (2022). doi:10.5109/6625724.
18) C. Harsito, M.R.A. Putra, D.A. Purba, and T. Triyono, "Mini review of thermoelectric and their potential applications as coolant in electric vehicles to improve system efficiency," *Evergreen*, **10** (*1*) 469–479 (2023). doi:10.5109/6782150.
19) W. Emar, Z. Al-Omari, and T. Rawashdeh, "Slip-ring induction motor torque and current ripple minimization using bang-bang current control," *Evergreen*, **10** (*2*) 962–975 (2023). doi:10.5109/6792891.
20) M. Ayundyahrini, D.A. Susanto, H. Febriansyah, F.M. Rizanulhaq, and G.H. Aditya, "Smart farming: integrated solar water pumping irrigation system in thailand," *Evergreen*, **10** (*1*) 553–563 (2023). doi:10.5109/6782161.
21) V. Singh, V.S. Yadav, M. Kumar, and N. Kumar, "Optimization and validation of solar pump performance by matlab simulink and rsm," *Evergreen*, **9** (*4*) 1110–1125 (2022). doi:10.5109/6625723.
22) V.C. Waila, A. Sharma, and M. Yusuf, "Optimizing the performance of solar pv water pump by using response surface methodology," *Evergreen*, **9** (*4*) 1151–1159 (2022). doi:10.5109/6625726.
23) T. Maftukhah, S. Wijonarko, D. Rustandi, S.W. Hidayat, J.A. Prakosa, E. Kartarajasa, and I.M. Siburian, "A method to present the uniqueness for uniform program applied in irrigation telecontrol," **10** (*03*) (2023).

24) A. Dhiman, and G. Sachdeva, "Energy and exergy analysis of a pressurized solar cooking system based on a parabolic dish collector," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, **09** 1168–1180 (2022).
25) R.A. Rouf, M.A. Hakim Khan, K.M. Ariful Kabir, and B.B. Saha, "Energy management and heat storage for solar adsorption cooling," *Evergreen*, **3** (*2*) 1–10 (2016). doi:10.5109/1800866.
26) D.A. Wulandari, Nasruddin, and E. Djubaedah, "Thermal behavior and characteristic of pangandaran natural zeolite," *Evergreen*, **6** (*3*) 225–229 (2019). doi:10.5109/2349298.
27) L.A. Rasheed, J.A.K. Mohammed, and R.A. Jessam, "Performance enhancement of a single pass solar air heater by adopting wire mesh absorber layer," *Evergreen*, **10** (*2*) 880–887 (2023). doi:10.5109/6792883.
28) R. Kumar, S.K. Verma, N.K. Gupta, and S.K. Singh, "Performance enhancement of tsah using graphene and graphene/ceo2 -black paint coating on absorber: a comparative study," *Evergreen*, **9** (*3*) 673–681 (2022). doi:10.5109/4843098.
29) S. Zaphar, M. Chandrashekara, and G. Verma, "Thermal analysis of an evacuated tube solar collector using a one-end stainless steel manifold for air heating applications under diverse operational conditions," *Evergreen*, **10** (*2*) 897–911 (2023). doi:10.5109/6792885.
30) K. Verma, O. Prakash, A.S. Paikra, and P. Tiwari, "Photovoltaic panel integration using phase change material (pcm): review," *Evergreen*, **10** (*1*) 444–453 (2023). doi:10.5109/6782147.
31) H.A. Jaffar, A.A. Ismaeel, and A.L. Shuraiji, "Review of hybrid photovoltaic- air updraft solar application: present and proposed state models," *Evergreen*, **9** (*4*) 1181–1202 (2022). doi:10.5109/6625729.
32) Y.S. Indartono, A.M. Nur, A. Divanto, and A. Adiyani, "Design and testing of thermosiphon passive cooling system to increase efficiency of floating photovoltaic array," *Evergreen*, **10** (*1*) 480–488 (2023). doi:10.5109/6782151.
33) A. Hassanzadeh, L. Jiang, and R. Winston, "Coupled optical-thermal modeling, design and experimental testing of a novel medium-temperature solar thermal collector with pentagon absorber," *Sol. Energy*, **173** 1248–1261 (2018). doi:10.1016/j.solener.2018.08.022.
34) L. Evangelisti, R. De Lieto Vollaro, and F. Asdrubali, "Latest advances on solar thermal collectors: a comprehensive review," *Renew. Sustain. Energy Rev.*, **114** 109318 (2019). doi:10.1016/j.rser.2019.109318.
35) M. Čekon, K. Struhala, and D. Kopkáně, "Preparation and characterization of a selective polymer-based solar absorber for building integration," *Appl. Sci. 2020, Vol. 10, Page 7861*, **10** (*21*) 7861 (2020). doi:10.3390/APP10217861.
36) L.B. López-Sosa, A. Ortíz-Carrión, D. Espinosa-Gómez, J. Zárate Medina, and M. González-Avilés, "Solar air heating system with low environmental impact materials: mathematical model and optothermal characterization," *Sustain. Energy Technol. Assessments*, **47** 101399 (2021). doi:10.1016/j.seta.2021.101399.
37) Z. Wang, T. Horseman, A.P. Straub, N.Y. Yip, D. Li, M. Elimelech, and S. Lin, "Pathways and challenges for efficient solar-thermal desalination," *Sci. Adv.*, **5** (*7*) (2019). doi:10.1126/SCIADV.AAX0763/SUPPL_FILE/AAX0763_SM.PDF.
38) B.P. Jelle, C. Breivik, and H. Drolsum Røkenes, "Building integrated photovoltaic products: a state-of-the-art review and future research opportunities," *Sol. Energy Mater. Sol. Cells*, **100** 69–96 (2012). doi:10.1016/J.SOLMAT.2011.12.016.
39) M. Debbarma, K. Sudhakar, and P. Baredar, "Thermal modeling, exergy analysis, performance of bipv and bipvt: a review," *Renew. Sustain. Energy Rev.*, **73** 1276–1288 (2017). doi:10.1016/J.RSER.2017.02.035.
40) H.M. Wilson, S. Rahman AR, T. Garg, and N. Jha, "Recycling of hazardous diesel soot particles into a high performance solar evaporation device," *Appl. Surf. Sci.*, **487** 951–961 (2019). doi:10.1016/J.APSUSC.2019.05.080.
41) F. Liu, B. Zhao, W. Wu, H. Yang, Y. Ning, Y. Lai, and R. Bradley, "Low cost, robust, environmentally friendly geopolymer-mesoporous carbon composites for efficient solar powered steam generation," *Adv. Funct. Mater.*, **28** (*47*) 1803266 (2018). doi:10.1002/adfm.201803266.
42) C. D'Alessandro, D. De Maio, M. Musto, D. De Luca, E. Di Gennaro, P. Bermel, and R. Russo, "Performance analysis of evacuated solar thermal panels with an infrared mirror," *Appl. Energy*, **288** 116603 (2021). doi:10.1016/J.APENERGY.2021.116603.
43) S. Shajan, and V. Baiju, "Designing a novel small-scale parabolic trough solar thermal collector with secondary reflector for uniform heat flux distribution," *Appl. Therm. Eng.*, **213** 118660 (2022). doi:10.1016/j.applthermaleng.2022.118660.
44) C.-Y. He, X.-H. Gao, D.-M. Yu, H.-X. Guo, S.-S. Zhao, and G. Liu, "Highly enhanced thermal robustness and photothermal conversion efficiency of solar-selective absorbers enabled by high-entropy alloy nitride motaticrn nanofilms," *ACS Appl. Mater. Interfaces*, **13** (*14*) 16987–16996 (2021). doi:10.1021/acsami.0c23011.
45) V. Pelenovich, X. Zeng, Y. Liu, X. Zhang, H. Liu, A. Pogrebnjak, R. Vildanov, B. Yang, and S. Liu, "AlCrO protected textured stainless-steel surface

for high temperature solar selective absorber applications," *Surf. Coatings Technol.*, **436** 128282 (2022). doi:10.1016/j.surfcoat.2022.128282.

46) R. Senthil, R. Madurai Elavarasan, R. Pugazhendhi, M. Premkumar, E. Vengadesan, S. Navakrishnan, M.R. Islam, and S.K. Natarajan, "A holistic review on the integration of heat pipes in solar thermal and photovoltaic systems," *Sol. Energy*, **227** 577–605 (2021). doi:10.1016/J.SOLENER.2021.09.036.

47) M.F. Hasan, M.S.U.R. Mahadi, T. Miyazaki, S. Koyama, and K. Thu, "Exergy analysis of serpentine thermosyphon solar water heater," *Appl. Sci. 2018, Vol. 8, Page 391*, **8** (*3*) 391 (2018). doi:10.3390/APP8030391.

48) Mohamad Waleed AlShaar, Zakaria Al-Omari, W. Emar, M. Alnsour, and G. Abu-Rumman, "Application of pv-thermal array for pumping irrigation water as an alternative to pv in ghor al-safi, jordan: a case study," *Evergreen*, **9** (*4*) 1140–1150 (2022). doi:10.5109/6625725.

49) A.K. Bohre, Y. Sawle, V.K. Jadoun, and A. Agarwal, "Assessment of techno-socio-economic performances of distribution network with optimal planning of multiple dgs," *Evergreen*, **10** (*2*) 1106–1112 (2023). doi:10.5109/6793670.

50) S.S. Mendu, P. Appikonda, A.K. Emadabathuni, and N. Koritala, "Techno-economic comparative analysis between grid-connected and stand-alone integrated energy systems for an educational institute," *Evergreen*, **7** (*3*) 382–395 (2020). doi:10.5109/4068616.

51) S.R. Atchuta, S. Sakthivel, and H.C. Barshilia, "Selective properties of high-temperature stable spinel absorber coatings for concentrated solar thermal application," *Sol. Energy*, **199** 453–459 (2020). doi:10.1016/j.solener.2020.02.048.

52) A. Palacios, C. Barreneche, M.E. Navarro, and Y. Ding, "Thermal energy storage technologies for concentrated solar power – a review from a materials perspective," *Renew. Energy*, **156** 1244–1265 (2020). doi:10.1016/j.renene.2019.10.127.

53) H. Chen, S.-L. Wu, H.-L. Wang, Q.-Y. Wu, and H.-C. Yang, "Photothermal devices for sustainable uses beyond desalination," *Adv. Energy Sustain. Res.*, **2** (*3*) 2000056 (2021). doi:10.1002/aesr.202000056.

54) H.M. Asfahan, M. Sultan, T. Miyazaki, B.B. Saha, A.A. Askalany, M.W. Shahzad, and W. Worek, "Recent development in adsorption desalination: a state of the art review," *Appl. Energy*, **328** 120101 (2022). doi:10.1016/j.apenergy.2022.120101.

55) Y.T. Abirham, K. Thu, T. Miyazaki, and N. Takata, "Comparative study of thermal water pumping cycles," *Evergreen*, **8** (*1*) 239–248 (2021). doi:10.5109/4372284.

56) Y. Iriani, R. Afriani, D.K. Sandi, and F. Nurosyid, "Co-precipitation synthesis and photocatalytic activity of mn-doped srtio3for the degradation of methylene blue wastewater," *Evergreen*, **9** (*4*) 1039–1045 (2022). doi:10.5109/6625717.

57) N. Moldakhanova, S. Alimkulov, and Z. Smagulov, "Analysis of changes in the ecological space of the ili river delta (due to reduced flow of the ili river)," *Evergreen*, **10** (*1*) 29–35 (2023). doi:10.5109/6781031.

58) H. Widiyandari, Y. Ayash, M.S. Al Ja'farawy, A. Subagio, and W.B. Widayatno, "Synthesis of wo3/pt nanoparticle by microwave-assisted sol-gel method for enhanced photocatalytic property in visible light," *Evergreen*, **10** (*1*) 139–145 (2023). doi:10.5109/6781060.

59) V.C. Hoang, T.-S. Bui, H.T.D. Nguyen, T.T. Hoang, G. Rahman, Q. Van Le, and D.L.T. Nguyen, "Solar-driven conversion of carbon dioxide over nanostructured metal-based catalysts in alternative approaches: fundamental mechanisms and recent progress," *Environ. Res.*, **202** 111781 (2021). doi:10.1016/j.envres.2021.111781.

60) M. Gao, L. Zhu, C.K. Peh, and G.W. Ho, "Solar absorber material and system designs for photothermal water vaporization towards clean water and energy production," *Energy Environ. Sci.*, **12** (*3*) 841–864 (2019). doi:10.1039/C8EE01146J.

61) B. Xie, E. Lovell, T.H. Tan, S. Jantarang, M. Yu, J. Scott, and R. Amal, "Emerging material engineering strategies for amplifying photothermal heterogeneous co2 catalysis," *J. Energy Chem.*, **59** 108–125 (2021). doi:10.1016/j.jechem.2020.11.005.

62) X. Wu, and E.K.L. Yeow, "Exploiting the upconversion luminescence, lewis acid catalytic and photothermal properties of lanthanide-based nanomaterials for chemical and polymerization reactions," *Phys. Chem. Chem. Phys.*, **24** (*19*) 11455–11470 (2022). doi:10.1039/D2CP00560C.

63) J. Li, W. Zhang, W. Ji, J. Wang, N. Wang, W. Wu, Q. Wu, X. Hou, W. Hu, and L. Li, "Near infrared photothermal conversion materials: mechanism, preparation, and photothermal cancer therapy applications," *J. Mater. Chem. B*, **9** (*38*) 7909–7926 (2021). doi:10.1039/D1TB01310F.

64) P. Wang, "Emerging investigator series: the rise of nano-enabled photothermal materials for water evaporation and clean water production by sunlight," *Environ. Sci. Nano*, **5** (*5*) 1078–1089 (2018). doi:10.1039/C8EN00156A.

65) H. Wang, R. Zhang, D. Yuan, S. Xu, and L. Wang, "Gas foaming guided fabrication of 3d porous plasmonic nanoplatform with broadband absorption, tunable shape, excellent stability, and high photothermal efficiency for solar water purification," *Adv. Funct. Mater.*, **30** (*46*) 2003995 (2020). doi:10.1002/adfm.202003995.

66) C. Chen, Y. Kuang, and L. Hu, “Challenges and opportunities for solar evaporation,” *Joule*, **3** (*3*) 683–718 (2019). doi:10.1016/j.joule.2018.12.023.

67) T. Boldoo, J. Ham, E. Kim, and H. Cho, “Review of the photothermal energy conversion performance of nanofluids, their applications, and recent advances,” *Energies 2020, Vol. 13, Page 5748*, **13** (*21*) 5748 (2020). doi:10.3390/EN13215748.

68) X. Cui, Q. Ruan, X. Zhuo, X. Xia, J. Hu, R. Fu, Y. Li, J. Wang, and H. Xu, “Photothermal nanomaterials: a powerful light-to-heat converter,” *Chem. Rev.*, (2023). doi:10.1021/acs.chemrev.3c00159.

69) C. Chen, L. Gong, W. Jiang, Z. Chen, W. Chen, X. Du, H. Zhou, Z. Huang, and H. Zhou, “Light-trapping carbon nanotube forests in glass fibre-reinforced thermoplastic prepregs for efficient laser-assisted automated fibre placement,” *Compos. Sci. Technol.*, **235** 109971 (2023). doi:10.1016/j.compscitech.2023.109971.

70) Z.-H. Zhou, C.-Y. He, and X.-H. Gao, “Recent advances of spectrally selective absorbers: materials, nanostructures, and photothermal power generation,” *APL Energy*, **2** (*1*) (2024). doi:10.1063/5.0194976.

71) J. Wang, Z. Wu, Y. Liu, S. Hou, Z. Ren, Y. Luo, X. Liu, J. Mao, Q. Zhang, and F. Cao, “An ultra-high temperature stable solar absorber using the zrc-based cermets,” *Front. Energy Res.*, **9** (2021). doi:10.3389/fenrg.2021.787237.

72) D.N. Thoai, Q.T. Hoai Ta, T.T. Truong, H. Van Nam, and G. Van Vo, “Review on the recent development and applications of three dimensional (3d) photothermal materials for solar evaporators,” *J. Clean. Prod.*, **293** 126122 (2021). doi:10.1016/j.jclepro.2021.126122.

73) C.-Y. He, X.-H. Gao, X.-L. Qiu, D.-M. Yu, H.-X. Guo, and G. Liu, “Scalable and ultrathin high-temperature solar selective absorbing coatings based on the high-entropy nanoceramic alcrwtanbtin with high photothermal conversion efficiency,” *Sol. RRL*, **5** (*4*) 2000790 (2021). doi:10.1002/solr.202000790.

74) D. Yan, and M. Li, “Stearic acid-modified mof-based composite phase change materials for solar-thermal energy conversion and storage,” *Sol. Energy*, **262** (*July*) 111843 (2023). doi:10.1016/j.solener.2023.111843.

75) T.-T.D. Pham, L.M.T. Phan, S. Cho, and J. Park, “Enhancement approaches for photothermal conversion of donor–acceptor conjugated polymer for photothermal therapy: a review,” *Sci. Technol. Adv. Mater.*, **23** (*1*) 707–734 (2022). doi:10.1080/14686996.2022.2134976.

76) G. Coccia, A. Aquilanti, S. Tomassetti, A. Ishibashi, and G. Di Nicola, “Design, manufacture and test of a low-cost solar cooker with high-performance light-concentrating lens,” *Sol. Energy*, **224** (*February*) 1028–1039 (2021). doi:10.1016/j.solener.2021.06.025.

77) C. Gao, Y. Li, L. Lan, Q. Wang, B. Zhou, Y. Chen, J. Li, J. Guo, and J. Mao, “Bioinspired asymmetric polypyrrole membranes with enhanced photothermal conversion for highly efficient solar evaporation,” *Adv. Sci.*, **11** (*6*) (2024). doi:10.1002/advs.202306833.

78) Z. Li, and C. Wang, “Novel advances in metal-based solar absorber for photothermal vapor generation,” *Chinese Chem. Lett.*, **31** (*9*) 2159–2166 (2020). doi:10.1016/j.cclet.2019.09.030.

79) J. Chen, Z. Ye, F. Yang, and Y. Yin, “Plasmonic nanostructures for photothermal conversion,” *Small Sci.*, **1** (*2*) 2000055 (2021). doi:10.1002/smsc.202000055.

80) S. Kaushik, A.K. Verma, S. Singh, N. Kanojia, S. Panwar, S. Kindo, S. Uniyal, S. Goswami, D. Som, and N.K. Yadav, “Comparative analysis of fluid flow attributes in rectangular shape micro channel having external rectangular inserts with hybrid al 2 o 3 + zno + h 2 o nano fluid and (h 2 o) base fluid,” *Evergreen*, **10** (*02*) 851–862 (2023). doi:https://doi.org/10.5109/6792839.

81) S. Kaushik, V. Uniyal, A.K. Verma, A.K. Jha, S. Joshi, M. Makhloga, P.S. Pargai, S.K. Sharma, R. Kumar, and S. Pal, “Comparative experimental and cfd analysis of fluid flow attributes in mini channel with hybrid cuo+zno+h2o nano fluid and (h2o) base fluid,” *Evergreen*, **10** (*1*) 182–195 (2023). doi:10.5109/6781069.

82) M.S.H. Ador, S. Kabir, F. Ahmed, F. Ahmad, and S. Adil, “Effects of minimum quantity lubrication (mql) on surface roughness in milling al alloy 383 / adc 12 using nano hybrid cutting fluid,” *Evergreen*, **9** (*4*) 1003–1020 (2022). doi:10.5109/6625790.

83) N.S. Fuzil, N.H. Othman, N.H. Alias, F. Marpani, M.H.D. Othman, A.F. Ismail, W.J. Lau, K. Li, T.D. Kusworo, I. Ichinose, and M.M.A. Shirazi, “A review on photothermal material and its usage in the development of photothermal membrane for sustainable clean water production,” *Desalination*, **517** 115259 (2021). doi:10.1016/j.desal.2021.115259.

84) C.-Y. He, X.-H. Gao, D.-M. Yu, S.-S. Zhao, H.-X. Guo, and G. Liu, “Toward high-temperature thermal tolerance in solar selective absorber coatings: choosing high entropy ceramic hfnbtatizrn,” *J. Mater. Chem. A*, **9** (*37*) 21270–21280 (2021). doi:10.1039/D1TA06682J.

85) K. Niranjan, A. Soum-Glaude, A. Carling-Plaza, S. Bysakh, S. John, and H.C. Barshilia, “Extremely high temperature stable nanometric scale multilayer spectrally selective absorber coating: emissivity measurements at elevated temperatures

and a comprehensive study on ageing mechanism," *Sol. Energy Mater. Sol. Cells*, **221** 110905 (2021). doi:10.1016/j.solmat.2020.110905.

86) M. Bello, and S. Shanmugan, "Achievements in mid and high-temperature selective absorber coatings by physical vapor deposition (pvd) for solar thermal application-a review," *J. Alloys Compd.*, **839** 155510 (2020). doi:10.1016/j.jallcom.2020.155510.

87) S.R. Atchuta, S. Sakthivel, and H.C. Barshilia, "Nickel doped cobaltite spinel as a solar selective absorber coating for efficient photothermal conversion with a low thermal radiative loss at high operating temperatures," *Sol. Energy Mater. Sol. Cells*, **200** 109917 (2019). doi:10.1016/j.solmat.2019.109917.

88) C.-Y. He, X.-H. Gao, D.-M. Yu, X.-L. Qiu, H.-X. Guo, and G. Liu, "Scalable and highly efficient high temperature solar absorber coatings based on high entropy alloy nitride alcrtatizrn with different antireflection layers," *J. Mater. Chem. A*, **9** (*10*) 6413–6422 (2021). doi:10.1039/D0TA09988K.

89) V. Aggarwal, A. Ranjan, S. Shaurya, and S.K. Garg, "To determine the futures pricing of metal commodities using deep learning," *Evergreen*, **10** (*2*) 1027–1033 (2023). doi:10.5109/6793658.

90) M. Valizade, M.M. Heyhat, and M. Maerefat, "Experimental comparison of optical properties of nanofluid and metal foam for using in direct absorption solar collectors," *Sol. Energy Mater. Sol. Cells*, **195** 71–80 (2019). doi:10.1016/j.solmat.2019.01.050.

91) M. Chen, Y. He, Q. Ye, and J. Zhu, "Tuning plasmonic near-perfect absorber for selective absorption applications," *Plasmonics*, **14** (*6*) 1357–1364 (2019). doi:10.1007/s11468-019-00925-w.

92) B. Liu, C. Wang, S. Bazri, I.A. Badruddin, Y. Orooji, S. Saeidi, S. Wongwises, and O. Mahian, "Optical properties and thermal stability evaluation of solar absorbers enhanced by nanostructured selective coating films," *Powder Technol.*, **377** 939–957 (2021). doi:10.1016/j.powtec.2020.09.040.

93) M. Bello, S. Subramani, and M.M. Bin Mohd Rashid, "The impact of fe3o4 on the performance of ultrathin ti/aln/ti tandem coating on stainless-steel for solar selective absorber application," *Results Phys.*, **19** 103582 (2020). doi:10.1016/j.rinp.2020.103582.

94) H. Zhong, H. Zhang, Z. Liu, X. Liu, and G. Liu, "Super-absorbers by randomly distributed titanium spheres," *IEEE Photonics Technol. Lett.*, **33** (*5*) 247–250 (2021). doi:10.1109/LPT.2021.3054333.

95) Y. Yang, T. Wang, T. Yao, G. Li, Y. Sun, X. Cao, L. Ma, and S. Peng, "Preparation of a novel tin/tinxoy/sio2 composite ceramic films on aluminum substrate as a solar selective absorber by magnetron sputtering," *J. Alloys Compd.*, **815** 152209 (2020). doi:10.1016/j.jallcom.2019.152209.

96) T.-L. Nguyen, C.-C. Chou, T.-H. Fang, and T.-C. Cheng, "Optical and thermal characteristics of porous anodic aluminum oxide for photothermal applications," *Sensors Mater.*, **34** (*1*) 55 (2022). doi:10.18494/SAM3545.

97) X. Ao, B. Li, B. Zhao, M. Hu, H. Ren, H. Yang, J. Liu, J. Cao, J. Feng, Y. Yang, Z. Qi, L. Li, C. Zou, and G. Pei, "Self-adaptive integration of photothermal and radiative cooling for continuous energy harvesting from the sun and outer space," *Proc. Natl. Acad. Sci.*, **119** (*17*) (2022). doi:10.1073/pnas.2120557119.

98) Y. Sun, J. Gao, Y. Liu, H. Kang, M. Xie, F. Wu, and H. Qiu, "Copper sulfide-macroporous polyacrylamide hydrogel for solar steam generation," *Chem. Eng. Sci.*, **207** 516–526 (2019). doi:10.1016/j.ces.2019.06.044.

99) B. Xu, J. Zhou, Z. Ni, C. Zhang, and C. Lu, "Synthesis of novel microencapsulated phase change materials with copper and copper oxide for solar energy storage and photo-thermal conversion," *Sol. Energy Mater. Sol. Cells*, **179** 87–94 (2018). doi:10.1016/j.solmat.2018.02.008.

100) Y. Wang, Q. Zhang, Y. Wang, L. V. Besteiro, Y. Liu, H. Tan, Z.M. Wang, A.O. Govorov, J.Z. Zhang, J.K. Cooper, J. Zhao, G. Chen, M. Chaker, and D. Ma, "Ultrastable plasmonic cu-based core–shell nanoparticles," *Chem. Mater.*, **33** (*2*) 695–705 (2021). doi:10.1021/acs.chemmater.0c04059.

101) D.E. Karas, J. Byun, J. Moon, and C. Jose, "Copper-oxide spinel absorber coatings for high-temperature concentrated solar power systems," *Sol. Energy Mater. Sol. Cells*, **182** 321–330 (2018). doi:10.1016/J.SOLMAT.2018.03.025.

102) M. Valizade, M.M. Heyhat, and M. Maerefat, "Experimental study of the thermal behavior of direct absorption parabolic trough collector by applying copper metal foam as volumetric solar absorption," *Renew. Energy*, **145** 261–269 (2020). doi:10.1016/J.RENENE.2019.05.112.

103) R. Kumar, and A. Dixit, "All oxide sol-gel assisted sio2/(zno/sn-in2o3)n/ss dielectric/conducting multilayer based spectrally selective coating on stainless steel tubes for potential solar thermal application," *Sol. Energy*, **236** 561–568 (2022). doi:10.1016/J.SOLENER.2022.03.032.

104) M. Kalsia, A. Sharma, R. Kaushik, and R.S. Dondapati, "Evaporative cooling technologies: conceptual review study," *Evergreen*, **10** (*1*) 421–429 (2023). doi:10.5109/6781102.

105) M.H. Mahmood, M. Sultan, T. Miyazaki, and S. Koyama, "Desiccant air-conditioning system for storage of fruits and vegetables: pakistan preview," *Evergreen*, **3** (*1*) 12–17 (2016). doi:10.5109/1657381.

106) P. Gupta, S. Zaman, F.T. Farin, and H.R. Ghosh,

“Effectiveness of cuo as selective coating on cu substrate obtained by dip coating method for solar thermal applications,” *Proc. Int. Conf. Electron. Commun. Inf. Technol. ICECIT 2021*, (2021). doi:10.1109/ICECIT54077.2021.9641267.

107) W.J. Kim, A. Mesbah, X. Deschanels, S. Bernard, and S. Lebègue, “First principles investigations of the optical selectivity of titanium carbide-based materials for concentrating solar power applications,” *J. Mater. Chem. C*, **9** (*24*) 7591–7598 (2021). doi:10.1039/D1TC01490K.

108) R. Kumar P, M.A. Hasan, A. Dey, and B. Basu, “Development of zrb$_2$-based single layer absorber coating and molten salt corrosion of bulk zrb$_2$–sic ceramic for concentrated solar power application,” *J. Phys. Chem. C*, **125** (*24*) 13581–13589 (2021). doi:10.1021/acs.jpcc.1c01984.

109) K. Xu, M. Du, L. Hao, J. Mi, Q. Yu, and S. Li, “A review of high-temperature selective absorbing coatings for solar thermal applications,” *J. Mater.*, **6** (*1*) 167–182 (2020). doi:10.1016/J.JMAT.2019.12.012.

110) D. Mateo, N. Morlanes, P. Maity, G. Shterk, O.F. Mohammed, and J. Gascon, “Efficient visible-light driven photothermal conversion of co$_2$ to methane by nickel nanoparticles supported on barium titanate,” *Adv. Funct. Mater.*, **31** (*8*) 2008244 (2021). doi:10.1002/adfm.202008244.

111) W.M.J. Karen, Z. Wang, W.Y.H. Liew, and G.J.H. Melvin, “Carbonized sawdust/barium titanate composite solar absorber for solar driven seawater desalination,” *Ceram. Int.*, **48** (*7*) 9939–9945 (2022). doi:10.1016/j.ceramint.2021.12.198.

112) M. Min, Y. Liu, C. Song, D. Zhao, X. Wang, Y. Qiao, R. Feng, W. Hao, P. Tao, W. Shang, J. Wu, and T. Deng, “Photothermally enabled pyro-catalysis of a batio$_3$ nanoparticle composite membrane at the liquid/air interface,” *ACS Appl. Mater. Interfaces*, **10** (*25*) 21246–21253 (2018). doi:10.1021/acsami.8b03411.

113) A.S. Alketbi, B. Yang, A. Raza, M. Zhang, J.-Y. Lu, Z. Wang, and T. Zhang, “Sputtered sic coatings for radiative cooling and light absorption,” *J. Photonics Energy*, **9** (*03*) 1 (2018). doi:10.1117/1.JPE.9.032703.

114) H. Kim, J. Ham, and H. Cho, “Evaluation of solar energy absorption and photo-thermal conversion performance of sic/ito hybrid nanofluid,” *Case Stud. Therm. Eng.*, **35** 102151 (2022). doi:10.1016/j.csite.2022.102151.

115) X. Wang, C. Zhang, K. Wang, Y. Huang, and Z. Chen, “Highly efficient photothermal conversion capric acid phase change microcapsule: silicon carbide modified melamine urea formaldehyde,” *J. Colloid Interface Sci.*, **582** 30–40 (2021). doi:10.1016/j.jcis.2020.08.014.

116) P. Wang, J.B. Li, L. Zhou, and K. Vafai, “Experimental characterization on pore parameter and the irradiation absorption efficiency of a series sic foam specimens,” *Energy Convers. Manag.*, **212** 112795 (2020). doi:10.1016/J.ENCONMAN.2020.112795.

117) A. Rodríguez-Palomo, E. Céspedes, D. Hernández-Pinilla, and C. Prieto, “High-temperature air-stable solar selective coating based on mosi2–si3n4 composite,” *Sol. Energy Mater. Sol. Cells*, **174** 50–55 (2018). doi:10.1016/j.solmat.2017.08.021.

118) A. Dan, K. Chattopadhyay, H.C. Barshilia, and B. Basu, “Shifting of the absorption edge in tib2/tib(n)/si3n4 solar selective coating for enhanced photothermal conversion,” *Sol. Energy*, **173** 192–200 (2018). doi:10.1016/j.solener.2018.07.002.

119) H. Wei, Q. Xu, D. Chen, M. Chen, M. Chang, and X. Ye, “Lowered infrared emittance and enhanced thermal stability of solar selective absorption properties of anodic aluminum oxide photonic crystal coatings,” *Sol. Energy*, **241** 592–600 (2022). doi:10.1016/j.solener.2022.06.041.

120) V. Bhalla, V. Khullar, and H. Tyagi, “Experimental investigation of photo-thermal analysis of blended nanoparticles (al2o3/co3o4) for direct absorption solar thermal collector,” *Renew. Energy*, **123** 616–626 (2018). doi:10.1016/j.renene.2018.01.042.

121) F. Qin, F. Xu, J. Liu, P. Hu, Z. Yi, L. Liu, H. Yang, J. Zhang, M. Pan, and P. Wu, “Broadband solar absorbers with excellent thermal radiation efficiency based on w–al2o3 stack of cubes,” *Int. J. Therm. Sci.*, **179** 107683 (2022). doi:10.1016/j.ijthermalsci.2022.107683.

122) D. Lou, A. Xu, Y. Fang, M. Cai, K. Lv, D. Zhang, X. Wang, Y. Huang, C. Li, and L. He, “Cobalt-Sputtered anodic aluminum oxide membrane for efficient photothermal co$_2$ hydrogenation,” *ChemNanoMat*, **7** (*9*) 1008–1012 (2021). doi:10.1002/cnma.202100162.

123) X. Pang, Y. Shen, J. Wei, and W. Yang, “Thermal stability and optical properties of single-layer nano-composite tin/tic-ni/mo solar-selective-absorbing coatings by laser cladding,” *Appl. Phys. A*, **125** (*10*) 677 (2019). doi:10.1007/s00339-019-2977-y.

124) H. Aréna, M. Coulibaly, A. Soum-Glaude, A. Jonchère, G. Arrachart, A. Mesbah, N. Pradeilles, M. Vandenhende, A. Maître, and X. Deschanels, “Effect of tic incorporation on the optical properties and oxidation resistance of sic ceramics,” *Sol. Energy Mater. Sol. Cells*, **213** 110536 (2020). doi:10.1016/j.solmat.2020.110536.

125) H. Aréna, M. Coulibaly, A. Soum-Glaude, A. Jonchère, A. Mesbah, G. Arrachart, N. Pradeilles, M. Vandenhende, A. Maitre, and X. Deschanels, “SiC-tic nanocomposite for bulk solar absorbers

applications: effect of density and surface roughness on the optical properties," *Sol. Energy Mater. Sol. Cells*, **191** 199–208 (2019). doi:10.1016/j.solmat.2018.11.018.

126) Y. Chen, C. Sha, W. Wang, and F. Yang, "Solar-driven steam generation on nitrogen-doped graphene in a 2d water path isolation system," *Mater. Res. Express*, **7** (*1*) (2019). doi:10.1088/2053-1591/ab625c.

127) S.-S. Zhao, X.-H. Gao, X.-L. Qiu, D.-M. Yu, and G.-K. Tian, "A novel tic-tin based spectrally selective absorbing coating: structure, optical properties and thermal stability," *Infrared Phys. Technol.*, **110** 103471 (2020). doi:10.1016/j.infrared.2020.103471.

128) M. Asadi, and S.M. Rozati, "Optical and structural properties of nanostructured copper oxide thin films as solar selective coating prepared by spray pyrolysis method," *Mater. Sci. Pol.*, **35** (*2*) 355–361 (2017). doi:10.1515/MSP-2017-0054.

129) N. Murugesan, S. Suresh, M. Kandasamy, S. Murugesan, and S.K. Kumar, "Facile preparation of reduced graphene oxide wrapped copper oxide thin film solar selective absorbers," *Ceram. Int.*, **46** (*17*) 27897–27902 (2020). doi:10.1016/J.CERAMINT.2020.07.143.

130) G.G. Welegergs, H.G. Gebretnisae, M.G. Tsegay, Z.Y. Nuru, S. Dube, and M. Maaza, "Thickness dependent morphological, structural and optical properties of ss/cuo nanocoatings as selective solar absorber," *Infrared Phys. Technol.*, **113** 103619 (2021). doi:10.1016/j.infrared.2020.103619.

131) W. He, L. Zhou, M. Wang, Y. Cao, X. Chen, and X. Hou, "Structure development of carbon-based solar-driven water evaporation systems," *Sci. Bull.*, **66** (*14*) 1472–1483 (2021). doi:10.1016/j.scib.2021.02.014.

132) X. Wu, G.Y. Chen, G. Owens, D. Chu, and H. Xu, "Photothermal materials: a key platform enabling highly efficient water evaporation driven by solar energy," *Mater. Today Energy*, **12** 277–296 (2019). doi:10.1016/j.mtener.2019.02.001.

133) G. Stando, D. Łukawski, F. Lisiecki, and D. Janas, "Intrinsic hydrophilic character of carbon nanotube networks," *Appl. Surf. Sci.*, **463** 227–233 (2019). doi:10.1016/j.apsusc.2018.08.206.

134) H.C. Barshilia, K. Niranjan, G. Srinivas, S. John, and N.T. Manikandanath, "On the thermal stability and performance evaluation of si doped transition metal nitride/oxide nanolayered multilayer-based spectrally selective absorber for high-temperature photothermal applications," *Sol. Energy Mater. Sol. Cells*, **241** 111746 (2022). doi:10.1016/j.solmat.2022.111746.

135) P. Cao, L. Zhao, J. Zhang, L. Zhang, P. Yuan, Y. Zhang, and Q. Li, "Gradient heating effect modulated by hydrophobic/hydrophilic carbon nanotube network structures for ultrafast solar steam generation," *ACS Appl. Mater. Interfaces*, **13** (*16*) 19109–19116 (2021). doi:10.1021/acsami.0c21831.

136) L.A. Al-Azez Mahdi, M.A. Fayad, and M.T. Chaichan, "Analysis of entropy generation for horizontal heated cylinder by natural convection and radiation," *Evergreen*, **10** (*2*) 888–896 (2023). doi:10.5109/6792884.

137) T. Huq, H.C. Ong, B.T. Chew, S.N. Kazi, M.N.M. Zubir, Z.C. Ong, and N.B.B.M. Azlan, "Graphene nanoplatelet nanofluids stabilised by hybridisation with graphene oxide: preparation, stability, and performance in flat plate solar thermal collector," *J. Therm. Anal. Calorim.*, **148** (*5*) 2105–2118 (2023). doi:10.1007/s10973-022-11866-8.

138) S. Mishra, A. Yadav, and P. Bhardwaj, "An experimental analysis of natural heat transfer between rectangular solid and perforated fins having different perforation characteristics," *Evergreen*, **10** (*1*) 366–371 (2023). doi:10.5109/6781094.

139) G. Zhu, L. Wang, Y. Zhang, W. Yu, and H. Xie, "Au–ag alloy nanoparticles supported on ordered mesoporous carbon (cmk-3) with remarkable solar thermal conversion efficiency," *Appl. Phys. A*, **125** (*2*) 151 (2019). doi:10.1007/s00339-019-2446-7.

140) F. Liu, D. Lou, E. Liang, Y. Gu, Z. Wang, X. Shi, R. Bradley, B. Zhao, and W. Wu, "Nanosecond laser patterned porous graphene from monolithic mesoporous carbon for high-performance solar thermal interfacial evaporation," *Adv. Mater. Technol.*, **6** (*12*) 2101052 (2021). doi:10.1002/admt.202101052.

141) Y. Chen, M. She, B. Wang, X. Wang, and X. Yan, "Preparation and photothermal properties of composite materials of gradient index glass and disordered mesoporous carbon," *J. Mater. Sci. Mater. Electron.*, **32** (*23*) 27534–27542 (2021). doi:10.1007/s10854-021-07128-2.

142) H. Zhou, C. Xue, Q. Chang, J. Yang, and S. Hu, "Assembling carbon dots on vertically aligned acetate fibers as ideal salt-rejecting evaporators for solar water purification," *Chem. Eng. J.*, **421** 129822 (2021). doi:10.1016/j.cej.2021.129822.

143) Q. Hou, C. Xue, N. Li, H. Wang, Q. Chang, H. Liu, J. Yang, and S. Hu, "Self-assembly carbon dots for powerful solar water evaporation," *Carbon N. Y.*, **149** 556–563 (2019). doi:10.1016/j.carbon.2019.04.083.

144) D. Kim, G. Jo, Y. Chae, S. Subramani, B.Y. Lee, E.J. Kim, M.-K. Ji, U. Sim, and H. Hyun, "Bioinspired *camellia japonica* carbon dots with high near-infrared absorbance for efficient photothermal cancer therapy," *Nanoscale*, **13** (*34*) 14426–14434 (2021). doi:10.1039/D1NR03999G.

145) J. Wan, J. Wang, H. Guo, K. Wan, X. Zhao, J. Li,

S. Li, Z. Chen, S. Liu, and K. Zhang, “Constructing ultra-stable, highly efficient and robust photothermal plastics assisted by solar-thermal carbon dots with photocaged reactivity,” *SSRN Electron. J.*, (2022). doi:10.2139/ssrn.4032069.

146) A. Pal, G. Natu, K. Ahmad, and A. Chattopadhyay, “Phosphorus induced crystallinity in carbon dots for solar light assisted seawater desalination,” *J. Mater. Chem. A*, **6** (*9*) 4111–4118 (2018). doi:10.1039/C7TA10224K.

147) A. Joseph, and S. Thomas, “Energy, exergy and corrosion analysis of direct absorption solar collector employed with ultra-high stable carbon quantum dot nanofluid,” *Renew. Energy*, **181** 725–737 (2022). doi:10.1016/j.renene.2021.09.079.

148) M. Zakaria, A.M. Sharaky, A.-S. Al-Sherbini, M. Bassyouni, M. Rezakazemi, and Y. Elhenawy, “Water desalination using solar thermal collectors enhanced by nanofluids,” *Chem. Eng. Technol.*, **45** (*1*) 15–25 (2022). doi:10.1002/ceat.202100339.

149) V. Bhalla, V. Khullar, and R.V. Parupudi, “Design and thermal analysis of nanofluid-based compound parabolic concentrator,” *Renew. Energy*, **185** 348–362 (2022). doi:10.1016/j.renene.2021.12.064.

150) P.G. Struchalin, V.S. Yunin, K.V. Kutsenko, O.V. Nikolaev, A.A. Vologzhannikova, M.P. Shevelyova, O.S. Gorbacheva, and B.V. Balakin, “Performance of a tubular direct absorption solar collector with a carbon-based nanofluid,” *Int. J. Heat Mass Transf.*, **179** 121717 (2021). doi:10.1016/j.ijheatmasstransfer.2021.121717.

151) F. Seifikar, and S. Azizian, “Super-stable carbon quantum dots nanofluid for efficient solar-thermal conversion,” *Energy Convers. Manag.*, **228** 113675 (2021). doi:10.1016/j.enconman.2020.113675.

152) A. Gimeno-Furió, R. Martínez-Cuenca, R. Mondragón, A.F.V. Gasulla, C. Doñate-Buendía, G. Mínguez-Vega, and L. Hernández, “Optical characterisation and photothermal conversion efficiency of a water-based carbon nanofluid for direct solar absorption applications,” *Energy*, **212** 118763 (2020). doi:10.1016/j.energy.2020.118763.

153) F.S. Awad, H.D. Kiriarachchi, K.M. AbouZeid, Ü. Özgür, and M.S. El-Shall, “Plasmonic graphene polyurethane nanocomposites for efficient solar water desalination,” *ACS Appl. Energy Mater.*, **1** (*3*) 976–985 (2018). doi:10.1021/acsaem.8b00109.

154) W. Hao, K. Chiou, Y. Qiao, Y. Liu, C. Song, T. Deng, and J. Huang, “Crumpled graphene ball-based broadband solar absorbers,” *Nanoscale*, **10** (*14*) 6306–6312 (2018). doi:10.1039/C7NR09556B.

155) F. Tao, Y. Zhang, B. Wang, F. Zhang, X. Chang, R. Fan, L. Dong, and Y. Yin, “Graphite powder/semipermeable collodion membrane composite for water evaporation,” *Sol. Energy Mater. Sol. Cells*, **180** 34–45 (2018). doi:10.1016/j.solmat.2018.02.014.

156) M. Simayee, A.I. zad, and A. Esfandiar, “Synergistic effect of reduced graphene oxide and carbon black as hybrid light absorber for efficient and antifouling texture-based solar steam generator,” *Sol. Energy*, **238** 226–237 (2022). doi:10.1016/j.solener.2022.04.042.

157) H. Yin, H. Xie, J. Liu, X. Zou, and J. Liu, “Graphene tube shaped photothermal layer for efficient solar-driven interfacial evaporation,” *Desalination*, **511** 115116 (2021). doi:10.1016/j.desal.2021.115116.

158) M. Mehrali, M.K. Ghatkesar, and R. Pecnik, “Full-spectrum volumetric solar thermal conversion via graphene/silver hybrid plasmonic nanofluids,” *Appl. Energy*, **224** 103–115 (2018). doi:10.1016/j.apenergy.2018.04.065.

159) S. Iranmanesh, M. Silakhori, M.S. Naghavi, B.C. Ang, H.C. Ong, and A. Esmaeilzadeh, “Using graphene nanoplatelets nanofluid in a closed-loop evacuated tube solar collector—energy and exergy analysis,” *J. Compos. Sci.*, **5** (*10*) 277 (2021). doi:10.3390/jcs5100277.

160) H. Shi, R. Gu, W. Xu, H. Huang, L. Xue, W. Wang, Y. Zhang, W. Si, and X. Dong, “Near-infrared light-harvesting fullerene-based nanoparticles for promoted synergetic tumor phototheranostics,” *ACS Appl. Mater. Interfaces*, **11** (*48*) 44970–44977 (2019). doi:10.1021/acsami.9b17716.

161) E.E. Barrera, A. Medina, L.G. Díaz-Barriga, A. Zacarías, J. de J. Rubio, G.L. Gutiérrez, J.M. Cruz, M. De Vega, N. García, and M. Venegas, “Performance assessment of low-temperature solar collector with fullerenes c60 manufactured at low cost in an emerging country,” *Appl. Sci.*, **12** (*6*) 3161 (2022). doi:10.3390/app12063161.

162) Z. Zhao, D. Wang, H. Gao, Z. Yang, H. Cao, and W. He, “Photoacoustic effect of near-infrared absorbing fullerene derivatives with click moieties,” *Dye. Pigment.*, **164** 182–187 (2019). doi:10.1016/j.dyepig.2019.01.022.

163) J. Li, F. Yu, Y. Jiang, L. Wang, X. Yang, X. Li, W. Lü, and X. Sun, “Photothermal diatomite/carbon nanotube combined aerogel for high-efficiency solar steam generation and wastewater purification,” *Sol. RRL*, **6** (*4*) 2101011 (2022). doi:10.1002/solr.202101011.

164) L. Guo, J. Gong, C. Song, Y. Zhao, B. Tan, Q. Zhao, and S. Jin, “Donor–acceptor charge migration system of superhydrophilic covalent triazine framework and carbon nanotube toward high performance solar thermal conversion,” *ACS Energy Lett.*, **5** (*4*) 1300–1306 (2020). doi:10.1021/acsenergylett.0c00394.

165) V.P. Prasadam, F. V. Ramirez, I. Papakonstantinou, I.P. Parkin, and N. Bahlawane, “Thermoresponsive black vo $_2$ –carbon nanotube composite coatings

for solar energy harvesting," *ACS Appl. Nano Mater.*, **3** (*9*) 8848–8857 (2020). doi:10.1021/acsanm.0c01630.

166) Q. Li, S. Zhang, N. Wei, R. Xu, X. Li, L. Gong, and H. Cui, "Porous ni/cnts composite membrane as solar absorber for highly efficient solar steam generation," *Sol. Energy Mater. Sol. Cells*, **243** 111815 (2022). doi:10.1016/j.solmat.2022.111815.

167) Z. Luo, X. Wang, D. Yang, S. Zhang, T. Zhao, L. Qin, and Z.-Z. Yu, "Photothermal hierarchical carbon nanotube/reduced graphene oxide microspherical aerogels with radially orientated microchannels for efficient cleanup of crude oil spills," *J. Colloid Interface Sci.*, **570** 61–71 (2020). doi:10.1016/j.jcis.2020.02.097.

168) X. Fan, Y. Yang, X. Shi, Y. Liu, H. Li, J. Liang, and Y. Chen, "A mxene-based hierarchical design enabling highly efficient and stable solar-water desalination with good salt resistance," *Adv. Funct. Mater.*, **30** (*52*) 2007110 (2020). doi:10.1002/adfm.202007110.

169) S. Singh, L. Nagdeve, H. Kumar, and K. Dhakar, "Rice straw based natural fiber reinforced polymer for sustainable bio- composites: a systematic review," *Evergreen*, **10** (*2*) 1041–1052 (2023). doi:10.5109/6793661.

170) Y. Kong, Y. Gao, Y. Sun, Y. Qi, W. Yin, S. Wang, F. Yin, Z. Dai, B. Gao, and Q. Yue, "Manipulating a vertical temperature-gradient of fe@ *enteromorpha* /graphene aerogel to enhanced solar evaporation and sterilization," *J. Mater. Chem. A*, **10** (*7*) 3750–3759 (2022). doi:10.1039/D1TA09807A.

171) Indriyati, I. Primadona, F.A. Permatasari, M.A. Irham, M. Nasir, and F. Iskandar, "Recent advances and rational design strategies of carbon dots towards highly efficient solar evaporation," *Nanoscale*, **13** (*16*) 7523–7532 (2021). doi:10.1039/D1NR00023C.

172) S. Sadripour, "3D numerical analysis of atmospheric-aerosol/carbon-black nanofluid flow within a solar air heater located in shiraz, iran," *Int. J. Numer. Methods Heat Fluid Flow*, **29** (*4*) 1378–1402 (2019). doi:10.1108/HFF-04-2018-0169.

173) A. Borode, N. Ahmed, and P. Olubambi, "A review of solar collectors using carbon-based nanofluids," *J. Clean. Prod.*, **241** 118311 (2019). doi:10.1016/j.jclepro.2019.118311.

174) K.Y. Leong, H.C. Ong, N.H. Amer, M.J. Norazrina, M.S. Risby, and K.Z. Ku Ahmad, "An overview on current application of nanofluids in solar thermal collector and its challenges," *Renew. Sustain. Energy Rev.*, **53** 1092–1105 (2016). doi:10.1016/j.rser.2015.09.060.

175) Z. Li, H. Lei, A. Kan, H. Xie, and W. Yu, "Photothermal applications based on graphene and its derivatives: a state-of-the-art review," *Energy*, **216** 119262 (2021). doi:10.1016/j.energy.2020.119262.

176) V.-D. Dao, N.H. Vu, and S. Yun, "Recent advances and challenges for solar-driven water evaporation system toward applications," *Nano Energy*, **68** 104324 (2020). doi:10.1016/j.nanoen.2019.104324.

177) C. Korupalli, P. Kalluru, K. Nuthalapati, N. Kuthala, S. Thangudu, and R. Vankayala, "Recent advances of polyaniline-based biomaterials for phototherapeutic treatments of tumors and bacterial infections," *Bioeng. 2020, Vol. 7, Page 94*, **7** (*3*) 94 (2020). doi:10.3390/BIOENGINEERING7030094.

178) Q. Hu, Z. Huang, Y. Duan, Z. Fu, and Bin Liu, "Reprogramming tumor microenvironment with photothermal therapy," *Bioconjug. Chem.*, **31** (*5*) 1268–1278 (2020). doi:10.1021/ACS.BIOCONJCHEM.0C00135/ASSET/IMAGES/MEDIUM/BC0C00135_0009.GIF.

179) H. Lin, H. Bai, Z. Yang, Q. Shen, M. Li, Y. Huang, F. Lv, and S. Wang, "Conjugated polymers for biomedical applications," *Chem. Commun.*, **58** (*52*) 7232–7244 (2022). doi:10.1039/D2CC02177C.

180) L. Ruiz-Pérez, L. Rizzello, J. Wang, N. Li, G. Battaglia, and Y. Pei, "Polypyrrole and polyaniline nanocomposites with high photothermal conversion efficiency," *Soft Matter*, **16** (*19*) 4569–4573 (2020). doi:10.1039/D0SM00306A.

181) S. Zhang, Z. Wu, Z. Liu, Y. Lv, and Z. Hu, "Nanostructured broadband solar absorber for effective photothermal conversion and electricity generation," *Energies 2022, Vol. 15, Page 1354*, **15** (*4*) 1354 (2022). doi:10.3390/EN15041354.

182) K. Wang, Z. Cheng, P. Li, Y. Zheng, Z. Liu, L. Cui, J. Xu, and J. Liu, "Three-dimensional self-floating foam composite impregnated with porous carbon and polyaniline for solar steam generation," *J. Colloid Interface Sci.*, **581** 504–513 (2021). doi:10.1016/j.jcis.2020.07.136.

183) J. Luo, L. Huo, L. Wang, X. Huang, J. Li, Z. Guo, Q. Gao, M. Hu, H. Xue, and J. Gao, "Superhydrophobic and multi-responsive fabric composite with excellent electro-photo-thermal effect and electromagnetic interference shielding performance," *Chem. Eng. J.*, **391** 123537 (2020). doi:10.1016/j.cej.2019.123537.

184) J. Guo, G. Lu, Y. Wang, Y. Yang, L. Yang, Y. Lin, Y. Tian, Q. Ni, S. Wang, and H. Ju, "Gold nanostar@polyaniline theranostic agent with high photothermal conversion efficiency for photoacoustic imaging- guided anticancer phototherapy at a low dosage," *ACS Appl. Mater. Interfaces*, **14** (*25*) 28570–28580 (2022). doi:10.1021/ACSAMI.2C05679/SUPPL_FILE/AM2C05679_SI_001.PDF.

185) G.Y. Ahn, T.H. Yun, J. Park, M.J. Lee, I. Choi, T.K. Ryu, K. Na, and S.W. Choi, "Polyaniline-

grafted nanodiamonds for efficient photothermal tumor therapy," *Colloids Surfaces B Biointerfaces*, **180** 273–280 (2019). doi:10.1016/J.COLSURFB.2019.04.063.

186) X. Zhao, J. Dong, X. Yu, L. Liu, J. Liu, and J. Pan, "Bioinspired photothermal polyaniline composite polyurethane sponge: interlayer engineering for high-concentration seawater desalination," *Sep. Purif. Technol.*, **311** 123181 (2023). doi:10.1016/J.SEPPUR.2023.123181.

187) D.P. Bhattarai, and B.S. Kim, "NIR-triggered hyperthermal effect of polythiophene nanoparticles synthesized by surfactant-free oxidative polymerization method on colorectal carcinoma cells," *Cells 2020, Vol. 9, Page 2122*, **9** (*9*) 2122 (2020). doi:10.3390/CELLS9092122.

188) J. Du, X. Bai, S. Wang, C. Li, E. Zhu, C. Liu, C. Ma, and H. Guo, "A novel polythiophene-conjugated polymer photocatalyst under visible light for killing multidrug-resistant bacteria," *Catal. Letters*, **154** (*4*) 1865–1883 (2024). doi:10.1007/s10562-023-04409-9.

189) J. Wang, X. Tan, X. Pang, L. Liu, F. Tan, and N. Li, "MoS 2 quantum dot@polyaniline inorganic–organic nanohybrids for in vivo dual-modal imaging guided synergistic photothermal/radiation therapy," *ACS Appl. Mater. Interfaces*, **8** (*37*) 24331–24338 (2016). doi:10.1021/acsami.6b08391.

190) Y. Zou, P. Yang, L. Yang, N. Li, G. Duan, X. Liu, and Y. Li, "Boosting solar steam generation by photothermal enhanced polydopamine/wood composites," *Polymer (Guildf).*, **217** 123464 (2021). doi:10.1016/j.polymer.2021.123464.

191) C. Lee, J.H. Park, M. Kim, J.S. Kim, and T.S. Shim, "Fabrication of a tunable photothermal actuator via in situ oxidative polymerization of polydopamine nanoparticles in hydrogel bilayers," *Soft Matter*, **18** (*24*) 4604–4612 (2022). doi:10.1039/D2SM00420H.

192) D. Khurana, Vikas, A.K. Shaw, and S. Soni, "Polydopamine coated gold nano blackbodies for tumor-selective spatial thermal damage during plasmonic photothermal cancer therapy," *IEEE Trans. Nanobioscience*, **21** (*4*) 482–489 (2022). doi:10.1109/TNB.2021.3118895.

193) Z. Zhang, J. Zhang, J. Tian, and H. Li, "A polydopamine nanomedicine used in photothermal therapy for liver cancer knocks down the anti-cancer target nedd8-e3 ligase roc1 (rbx1)," *J. Nanobiotechnology*, **19** (*1*) 323 (2021). doi:10.1186/s12951-021-01063-4.

194) Y. Li, H. Xu, H. Li, and S. Zhong, "Controlled preparation and photothermal properties of polydopamine submicrospheres," *Inorg. Chem. Commun.*, **124** 108395 (2021). doi:10.1016/j.inoche.2020.108395.

195) J. Su, T. Liao, Z. Ren, Y. Kuang, W. Yu, Q. Qiao, B. Jiang, X. Chen, Z. Xu, and C. Li, "Polydopamine nanoparticles coated with a metal-polyphenol network for enhanced photothermal/chemodynamic cancer combination therapy," *Int. J. Biol. Macromol.*, **238** 124088 (2023). doi:10.1016/j.ijbiomac.2023.124088.

196) C. Xiao, W. Liang, Q.-M. Hasi, L. Chen, J. He, F. Liu, C. Wang, H. Sun, Z. Zhu, and A. Li, "Ag/polypyrrole co-modified poly(ionic liquid)s hydrogels as efficient solar generators for desalination," *Mater. Today Energy*, **16** 100417 (2020). doi:10.1016/j.mtener.2020.100417.

197) X. Zang, H. Ma, Y. Sun, Y. Tang, J. Ji, and M. Xue, "Integrated polypyrrole-based smart clothing with photothermal conversion and thermosensing functions for wearable applications," *Langmuir*, **38** (*32*) 9967–9973 (2022). doi:10.1021/acs.langmuir.2c01278.

198) J. Wu, X. Xu, X. Guo, W. Xie, L. Pan, and Y. Chen, "Polypyrrole modification on bivo4 for photothermal-assisted photoelectrochemical water oxidation," *J. Chem. Phys.*, **158** (*9*) (2023). doi:10.1063/5.0130217.

199) C. Liu, Y. Wan, Y. Gao, C. Dong, and X. Chen, "Polypyrrole-coated expanded graphite-based phase change materials for photothermal energy storage," *Mater. Today Nano*, **23** 100376 (2023). doi:10.1016/j.mtnano.2023.100376.

200) H. Zeng, P. Wang, L. Liang, H. Hu, Y. Peng, X. Li, and C. Liu, "Facile preparation of superhydrophobic cotton fabric with a photothermal conversion effect via polypyrrole deposition for oil/water separation," *J. Environ. Chem. Eng.*, **10** (*1*) 106915 (2022). doi:10.1016/j.jece.2021.106915.

201) Q. Zhao, Y. Wan, F. Chang, Y. Wang, H. Jiang, L. Jiang, X. Zhang, and N. Ma, "Photothermal converting polypyrrole/polyurethane composite foams for effective solar desalination," *Desalination*, **527** 115581 (2022). doi:10.1016/j.desal.2022.115581.

202) H. Geng, E.J. Lupton, Y. Ma, R. Sun, C.L. Grigsby, G. Brachi, X. Li, K. Zhou, D.J. Stuckey, and M.M. Stevens, "Hybrid polypyrrole and polydopamine nanosheets for precise raman/photoacoustic imaging and photothermal therapy," *Adv. Healthc. Mater.*, **12** (*27*) (2023). doi:10.1002/adhm.202301148.

203) L. Hu, X. Li, L. Ding, L. Chen, X. Zhu, Z. Mao, X. Feng, X. Sui, and B. Wang, "Flexible textiles with polypyrrole deposited phase change microcapsules for efficient photothermal energy conversion and storage," *Sol. Energy Mater. Sol. Cells*, **224** 110985 (2021). doi:10.1016/j.solmat.2021.110985.

204) P. Xiao, J. Gu, C. Zhang, F. Ni, Y. Liang, J. He, L. Zhang, J. Ouyang, S.-W. Kuo, and T. Chen, "A scalable, low-cost and robust photo-thermal fabric

with tunable and programmable 2d/3d structures towards environmentally adaptable liquid/solid-medium water extraction," *Nano Energy*, **65** 104002 (2019). doi:10.1016/j.nanoen.2019.104002.

205) Y. Wang, S. Li, P. Zhang, H. Bai, L. Feng, F. Lv, L. Liu, and S. Wang, "Photothermal-responsive conjugated polymer nanoparticles for remote control of gene expression in living cells," *Adv. Mater.*, **30** (*8*) 1705418 (2018). doi:10.1002/adma.201705418.

206) A.H. Wibowo, H. Al Arraf, A. Masykur, F. Rahmawati, M. Firdaus, F. Pasila, U. Farahdina, and N. Nasori, "Composite of polyaniline/reduced graphene oxide with the single-, bi- and tri- metal oxides modification and the effect on the capacitance properties," *Evergreen*, **10** (*1*) 85–93 (2023). doi:10.5109/6781053.

207) L. Fu, Z. Huang, X. Zhou, L. Deng, M. Liao, S. Chen, H. Wang, and L. Wang, "Waste tissue-based bilayer solar evaporator for efficient solar photothermal generation of clean water," *Environ. Technol.*, 1–11 (2022). doi:10.1080/09593330.2022.2082326.

208) Y. Wang, H.-M. Meng, G. Song, Z. Li, and X.-B. Zhang, "Conjugated-polymer-based nanomaterials for photothermal therapy," *ACS Appl. Polym. Mater.*, **2** (*10*) 4258–4272 (2020). doi:10.1021/acsapm.0c00680.

209) Q. Pang, K. Wu, Z. Jiang, Z. Shi, Z. Si, Q. Wang, Y. Cao, R. Hou, and Y. Zhu, "A polyaniline nanoparticles crosslinked hydrogel with excellent photothermal antibacterial and mechanical properties for wound dressing," *Macromol. Biosci.*, **22** (*3*) 2100386 (2022). doi:10.1002/mabi.202100386.

210) Y. Zhang, F. Fang, Y. Chen, M. Li, L. Li, W. Li, and J. Zhang, "Hollow mesoporous polyaniline nanoparticles with high drug payload and robust photothermal capability for cancer combination therapy," *Chinese J. Chem. Eng.*, **38** 221–228 (2021). doi:10.1016/j.cjche.2021.03.011.

211) W. Li, J.X. Fan, D.W. Zheng, and X.Z. Zhang, "Tumor antigen loaded nanovaccine induced nir-activated inflammation for enhanced antigen presentation during immunotherapy of tumors," *Small*, **18** (*49*) 2205193 (2022). doi:10.1002/SMLL.202205193.

212) M. Farokhi, F. Mottaghitalab, M.R. Saeb, and S. Thomas, "Functionalized theranostic nanocarriers with bio-inspired polydopamine for tumor imaging and chemo-photothermal therapy," *J. Control. Release*, **309** 203–219 (2019). doi:10.1016/J.JCONREL.2019.07.036.

213) Z. Wang, W. Wang, M. Wamsley, D. Zhang, and H. Wang, "Colloidal polydopamine beads: a photothermally active support for noble metal nanocatalysts," *ACS Appl. Mater. Interfaces*, **14** (*15*) 17560–17569 (2022). doi:10.1021/acsami.2c03183.

214) Yin Wujie;, Zhuang Jiayi;, Qin Qianru;, Yang Jiawen;, Jing Danni;, Chen Jiao;, and Wang Yang, "Synthesis of core-shell nanostructured cu 2-x se @pda nanoparticles and application for photothermal therapy of tumor," *Hans J. Nanotechnol.*, **12** (*03*) 89–96 (2022). doi:10.12677/NAT.2022.123011.

215) C. Su, H. Zhong, H. Chen, Y. Guo, Z. Guo, D. Huang, W. Zhang, Q. Wu, B. Yang, and Z. Liu, "Black phosphorus–polypyrrole nanocomposites for high-performance photothermal cancer therapy," *New J. Chem.*, **43** (*22*) 8620–8626 (2019). doi:10.1039/C9NJ01249D.

216) X. Shan, Q. Chen, X. Yin, C. Jiang, T. Li, S. Wei, X. Zhang, G. Sun, J. Liu, and L. Lu, "Polypyrrole-based double rare earth hybrid nanoparticles for multimodal imaging and photothermal therapy," *J. Mater. Chem. B*, **8** (*3*) 426–437 (2020). doi:10.1039/C9TB02254F.

217) C. Zhang, H. Pan, X. Wang, and S.-K. Sun, "Microwave-assisted ultrafast fabrication of high-performance polypyrrole nanoparticles for photothermal therapy of tumors *in vivo*," *Biomater. Sci.*, **6** (*10*) 2750–2756 (2018). doi:10.1039/C8BM00653A.

218) W. Zeng, X. Wu, T. Chen, S. Sun, Z. Shi, J. Liu, X. Ji, X. Zeng, J. Guan, L. Mei, and M. Wu, "Renal-Clearable ultrasmall polypyrrole nanoparticles with size-regulated property for second near-infrared light-mediated photothermal therapy," *Adv. Funct. Mater.*, **31** (*15*) 2008362 (2021). doi:10.1002/adfm.202008362.

219) X. Sun, J. Wang, Z. Wang, C. Zhu, J. Xi, L. Fan, J. Han, and R. Guo, "Gold nanorod@void@polypyrrole yolk@shell nanostructures: synchronous regulation of photothermal and drug delivery performance for synergistic cancer therapy," *J. Colloid Interface Sci.*, **610** 89–97 (2022). doi:10.1016/j.jcis.2021.11.189.

220) W. Huang, T. Leng, M. Gao, Q. Hu, L. Liu, and H. Dou, "Scalable dextran-polypyrrole nano-assemblies with photothermal/photoacoustic dual capabilities and enhanced biocompatibility," *Carbohydr. Polym.*, **241** 116224 (2020). doi:10.1016/j.carbpol.2020.116224.

221) X. Wang, D. Yang, X. An, and X. Qian, "Phytic acid doped polypyrrole as a mediating layer promoting growth of prussian blue on cotton fibers for solar-driven interfacial water evaporation," *Polymers (Basel).*, **14** (*1*) 6 (2021). doi:10.3390/polym14010006.

222) Y. Fan, W. Bai, P. Mu, Y. Su, Z. Zhu, H. Sun, W. Liang, and A. Li, "Conductively monolithic polypyrrole 3-d porous architecture with micron-

sized channels as superior salt-resistant solar steam generators," *Sol. Energy Mater. Sol. Cells*, **206** 110347 (2020). doi:10.1016/j.solmat.2019.110347.

223) Y. Xu, J. Wang, F. Yu, Z. Guo, H. Cheng, J. Yin, L. Yan, and X. Wang, "Flexible and efficient solar thermal generators based on polypyrrole coated natural latex foam for multimedia purification," *ACS Sustain. Chem. Eng.*, **8** (*32*) 12053–12062 (2020). doi:10.1021/acssuschemeng.0c03164.

224) Y. Chen, G. Zhao, L. Ren, H. Yang, X. Xiao, and W. Xu, "Blackbody-inspired array structural polypyrrole-sunflower disc with extremely high light absorption for efficient photothermal evaporation," *ACS Appl. Mater. Interfaces*, **12** (*41*) 46653–46660 (2020). doi:10.1021/acsami.0c11549.

225) C. Xiao, L. Chen, P. Mu, J. Jia, H. Sun, Z. Zhu, W. Liang, and A. Li, "Sugarcane-Based photothermal materials for efficient solar steam generation," *ChemistrySelect*, **4** (*27*) 7891–7895 (2019). doi:10.1002/slct.201901889.

226) Y. Li, L. Xu, J. Cai, J. Liu, B. Lv, J. Chao, Q. Zhang, and Y. Zhao, "A stable bilayer polypyrrole-sorghum straw evaporator for efficient solar steam generation and desalination," *Adv. Sustain. Syst.*, **6** (*3*) 2100342 (2022). doi:10.1002/adsu.202100342.

227) M. Zhang, F. Xu, W. Liu, Y. Hou, L. Su, X. Zhang, R. Zhang, L. Zhou, X. Yan, M. Wang, X. Hou, and Y. Cao, "Antibacterial evaporator based on reduced graphene oxide/polypyrrole aerogel for solar-driven desalination," *Nano Res.*, (2022). doi:10.1007/s12274-021-4041-4.

228) J.U. Kim, S. Lee, S.J. Kang, and T. Kim, "Materials and design of nanostructured broadband light absorbers for advanced light-to-heat conversion," *Nanoscale*, **10** (*46*) 21555–21574 (2018). doi:10.1039/C8NR06024J.

229) Z. Lin, T. Wu, J. Shi, B. Zhou, C. Zhu, Y. Wang, R. Liang, and M. Mizuno, "Poly (n -phenylglycine)-based bioinspired system for stably and efficiently enhancing solar evaporation," *ACS Sustain. Chem. Eng.*, **9** (*1*) 448–457 (2021). doi:10.1021/acssuschemeng.0c07608.

230) Z. Lin, T. Wu, Y.-F. Feng, J. Shi, B. Zhou, C. Zhu, Y. Wang, R. Liang, and M. Mizuno, "Poly(n -phenylglycine)/mos 2 nanohybrid with synergistic solar-thermal conversion for efficient water purification and thermoelectric power generation," *ACS Appl. Mater. Interfaces*, **14** (*1*) 1034–1044 (2022). doi:10.1021/acsami.1c20393.

231) C. Liu, X. Guo, C. Ruan, H. Hu, B.-P. Jiang, H. Liang, and X.-C. Shen, "An injectable thermosensitive photothermal-network hydrogel for near-infrared-triggered drug delivery and synergistic photothermal-chemotherapy," *Acta Biomater.*, **96** 281–294 (2019). doi:10.1016/j.actbio.2019.07.024.

232) N.K. Yadav, N.S. Rajput, S. Kulshreshtha, and M.K. Gupta, "Investigation of the mechanical and wear properties of epoxy resin composite (ercs) made with nano particle tio2 and cotton fiber reinforcement," *Evergreen*, **10** (*1*) 63–77 (2023). doi:10.5109/6781041.

233) S. Singh, S.K. Singh, R. Kumar, A. Shrama, and S. Kanga, "Finding alternative to river sand in building construction," *Evergreen*, **9** (*4*) 973–992 (2022). doi:10.5109/6625713.

234) J.S. Budi, Ubaidillah, A.R. Prabowo, A. Esdiyanto, Z. Arifin, and Z.E. Priyatama, "Numerical analysis of bifilar coil geometry on induction heating performance for self-healing asphalt," *Evergreen*, **10** (*1*) 574–584 (2023). doi:10.5109/6782164.

235) J.L. Concha, and J. Norambuena-Contreras, "Thermophysical properties and heating performance of self-healing asphalt mixture with fibres and its application as a solar collector," *Appl. Therm. Eng.*, **178** 115632 (2020). doi:10.1016/j.applthermaleng.2020.115632.

236) X. Ye, Z. Tian, X. Cao, Y. Fan, P. Zhou, C. Wang, J. Li, H. Sun, Z. Zhu, W. Liang, and A. Li, "Fatty amines embedded carbon membranes with aligned nanochannels network: a device with extremely high photothermal conversion efficiency toward solar energy harvesting and storage," *Sol. RRL*, **6** (*4*) (2022). doi:10.1002/solr.202100924.

237) C. Peng, D. Yang, Z. You, D. Ruan, P. Guan, Z. Ye, Y. Ning, N. Zhao, and F. Yang, "A photothermal and superhydrophobic emulsified asphalt coating modified by cnts and ptfe for anti-icing and de-icing applications," *Constr. Build. Mater.*, **416** 135148 (2024). doi:10.1016/j.conbuildmat.2024.135148.

238) Y. Cui, L. Zhang, C. Xing, and Y. Tan, "Anti-icing properties and application of superhydrophobic coatings on asphalt pavement," *Constr. Build. Mater.*, **419** 135452 (2024). doi:10.1016/j.conbuildmat.2024.135452.

239) M. Fan, W. Zhang, E. Huang, J. Liu, S. Liu, S. Chai, and L. Gong, "Sandy sediment-based solar evaporator for large-scale and scalable freshwater production under various water environments," *Sol. Energy*, **269** 112333 (2024). doi:10.1016/j.solener.2024.112333.

240) F. Ni, P. Xiao, N. Qiu, C. Zhang, Y. Liang, J. Gu, J. Xia, Z. Zeng, L. Wang, Q. Xue, and T. Chen, "Collective behaviors mediated multifunctional black sand aggregate towards environmentally adaptive solar-to-thermal purified water harvesting," *Nano Energy*, **68** 104311 (2020). doi:10.1016/j.nanoen.2019.104311.

241) S. Li, L. Li, F. Tang, T. Sui, Z. Chang, K. Li, and J. Mu, "Construction of quartz sand@g-c3n4/cofe-ldh core/shell heterostructures for boosted visible-light driven photothermal-assisted photocatalytic

wastewater purification," *Appl. Surf. Sci.*, **656** 159656 (2024). doi:10.1016/j.apsusc.2024.159656.

242) M.E.H. Attia, A.E. Kabeel, M. Abdelgaied, M.M. Abdel-Aziz, A. Bellila, and A. Abdullah, "Optimal size of black gravel as energy storage materials for performance improvement of hemispherical distillers," *J. Energy Storage*, **43** 103196 (2021). doi:10.1016/J.EST.2021.103196.

243) M. Elashmawy, "Improving the performance of a parabolic concentrator solar tracking-tubular solar still (pcst-tss) using gravel as a sensible heat storage material," *Desalination*, **473** 114182 (2020). doi:10.1016/J.DESAL.2019.114182.

244) A.F. Mohamed, A.A. Hegazi, G.I. Sultan, and E.M.S. El-Said, "Enhancement of a solar still performance by inclusion the basalt stones as a porous sensible absorber: experimental study and thermo-economic analysis," *Sol. Energy Mater. Sol. Cells*, **200** 109958 (2019). doi:10.1016/j.solmat.2019.109958.

245) A. Sarifudin, I. Yaningsih, B. Kristiawan, A. Wibawa, T. Miyazaki, K. Thu, A.S. Silitonga, and H.C. Ong, "Investigation of granular natural stone materials as photothermal absorbers for sustainable and environmentally friendly energy harvesting," *J. Appl. Eng. Sci.*, 1–16 (2024). doi:10.5937/jaes0-47834.

246) A. Bilal, B. Jamil, N.U. Haque, and M.A. Ansari, "Investigating the effect of pumice stones sensible heat storage on the performance of a solar still," *Groundw. Sustain. Dev.*, **9** 100228 (2019). doi:10.1016/J.GSD.2019.100228.

247) T. Arunkumar, J. Wang, D. Dsilva Winfred Rufuss, D. Denkenberger, and A.E. Kabeel, "Sensible desalting: investigation of sensible thermal storage materials in solar stills," *J. Energy Storage*, **32** 101824 (2020). doi:10.1016/j.est.2020.101824.

248) N. Channa Keshava Naik, and K.S. Shashi Shekar, "Evaluation and comparison of performance of a solar pebble absorber collector with a conventional flat plate collector," *Mater. Today Proc.*, **52** 266–273 (2022). doi:10.1016/j.matpr.2021.08.025.

249) R. Dhivagar, B. Deepanraj, M. Mohanraj, and H. Chyuan Ong, "Second law based thermodynamic analysis of crushed gravel sand and biomass evaporator assisted solar still," *Sustain. Energy Technol. Assessments*, **52** 102160 (2022). doi:10.1016/j.seta.2022.102160.

250) D.P. Sari, A. Sumarno, A.M. Prasetyo, and L.N. Ngeljaratan, "Energy conservation techniques in tropical climate - a comprehensive review and adaptation of the lamin house for nusantara," *Evergreen*, **10** (*03*) (2023).

251) K.T. Zingre, X. Yang, and M.P. Wan, "Performance analysis of cool roof, green roof and thermal insulation on a concrete flat roof in tropical climate," *Evergreen*, **2** (*2*) 34–43 (2015). doi:10.5109/1544078.

252) H. Koide, T. Seiichi, K. Tamura, W. Jung, H. Nakayama, S. Matsuda, and K. Moroga, "Possibility of cooperation for a low carbon society: comparison of the fukuoka and busan metropolitan cities," *Evergr. Jt. J. Nov. Carbon Resour. Sci. Green Asia Strateg.*, **2** 21–35 (2010). http://jointfukuoka.seesaa.net/.

253) S. Hori, "Implications of energy efficiency and economic growth in developing countries," *Evergr. J. Nov. Carbon Resour. Sci.*, **6** 9–14 (2012).

254) G. Zhakypova, S. Uderbayev, N. Saktaganova, G. Abyieva, A. Budikova, and A. Zhapakhova, "Properties of fine-grained concrete using ash of kazakhstan," *Evergreen*, **10** (*2*) 830–841 (2023). doi:10.5109/6792835.

255) B. Rusdyanto, F. Imaduddin, Ubaidillah, and D. Ariawan, "The tensile properties of recycled polypropylene filament (rpp) as 3d printing material," *Evergreen*, **10** (*1*) 489–495 (2023). doi:10.5109/6782152.

256) Y. Adityawardhana, A.Z. Syahrial, and B. Adjiantoro, "Characteristic of aa 7075-reinforced nano-sic composites produced by stir-squeeze casting and open die cold forging as an armor material candidate," *Evergreen*, **10** (*2*) 722–730 (2023). doi:10.5109/6792821.

257) S. Kumar, Akash, K.C. Anil, and J. Kumaraswamy, "Solid particle erosion performance of multi-layered carbide coatings (wc-sic-cr3c2)," *Evergreen*, **10** (*2*) 813–819 (2023). doi:10.5109/6792833.

258) T. Park, J. Yeo, M. Seo, J. Miyawaki, I. Mochida, and S. Yoon, "Hybridization of silicon / carbon composites with natural graphite for improving anodic performances of lithium-ion batteries," **6** 24–28 (2012).

259) S.S. Salvi, V. Bhalla, R.A. Taylor, V. Khullar, T.P. Otanicar, P.E. Phelan, and H. Tyagi, "Technological advances to maximize solar collector energy output: a review," *J. Electron. Packag. Trans. ASME*, **140** (*4*) (2018). doi:10.1115/1.4041219/457305.

260) X. Fan, B. Lv, Y. Xu, H. Huang, Y. Yang, Y. Wang, J. Xiao, and C. Song, "Electrospun reduced graphene oxide/polyacrylonitrile membrane for high-performance solar evaporation," *Sol. Energy*, **209** 325–333 (2020). doi:10.1016/j.solener.2020.09.013.

261) A. Li, J. Xiong, Y. Liu, L. Wang, X. Qin, and J. Yu, "A rapid-ab/desorption and portable photothermal mil-101(cr) nanofibrous composite membrane fabricated by spray-electrospinning for atmosphere water harvesting," *ENERGY Environ. Mater.*, (2022). doi:10.1002/eem2.12254.

262) H. Fan, A. Gao, G. Zhang, S. Zhao, J. Cui, and Y. Yan, "A design of bifunctional photothermal layer

on polysulfone membrane with enclosed cellular-like structure for efficient solar steam generation," *Chem. Eng. J.*, **415** 128798 (2021). doi:10.1016/j.cej.2021.128798.

263) W. Li, Y. Chen, L. Yao, X. Ren, Y. Li, and L. Deng, "Fe3O4/pvdf-hfp photothermal membrane with in-situ heating for sustainable, stable and efficient pilot-scale solar-driven membrane distillation," *Desalination*, **478** 114288 (2020). doi:10.1016/j.desal.2019.114288.

264) M. Xia, J. Wei, Z. Han, Q. Tian, C. Xiao, Q.-M. Hasi, Y. Zhang, and L. Chen, "An integrated solar absorber with salt-resistant and oleophobic based on pvdf composite membrane for solar steam generation," *Mater. Today Energy*, **25** 100959 (2022). doi:10.1016/j.mtener.2022.100959.

265) B. Gong, H. Yang, S. Wu, G. Xiong, J. Yan, K. Cen, Z. Bo, and K. Ostrikov, "Graphene array-based anti-fouling solar vapour gap membrane distillation with high energy efficiency," *Nano-Micro Lett.*, **11** (*1*) 51 (2019). doi:10.1007/s40820-019-0281-1.