

## A Comparative Study of Cooling radiator Coatings with Nanomaterials as a Function of Time and Solar Radiation in Baghdad

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### Abstract

This study investigates the thermal performance of cooling radiator coated with an epoxy-based nanocomposite containing aluminum oxide ( $\text{Al}_2\text{O}_3$ ) and titanium dioxide ( $\text{TiO}_2$ ) nanoparticles, compared with pipes coated with epoxy only. Experiments were conducted under real outdoor solar conditions in Baghdad during February and March. Outlet water temperature, surface temperature, ambient temperature, and solar radiation intensity were measured at different times of the day. Surface temperature data were analyzed using the Stefan–Boltzmann radiation model to estimate the relative emissivity of the coatings. The results reveal a dual thermal behavior of the nanocoated pipes: enhanced heat absorption at moderate solar radiation and increased radiative heat losses at higher irradiance levels. A relative emissivity ratio of approximately 1.05–1.08 was obtained for the nanocoating compared with epoxy, explaining the reduced net heat transfer to water at peak solar radiation. These findings confirm that emissivity plays a key role in determining the thermal efficiency of nanocoated pipes in solar thermal applications.

**Keywords:** Nanoparticles coating, Thermal Conductivity, Solar thermal Energy.

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## Introduction

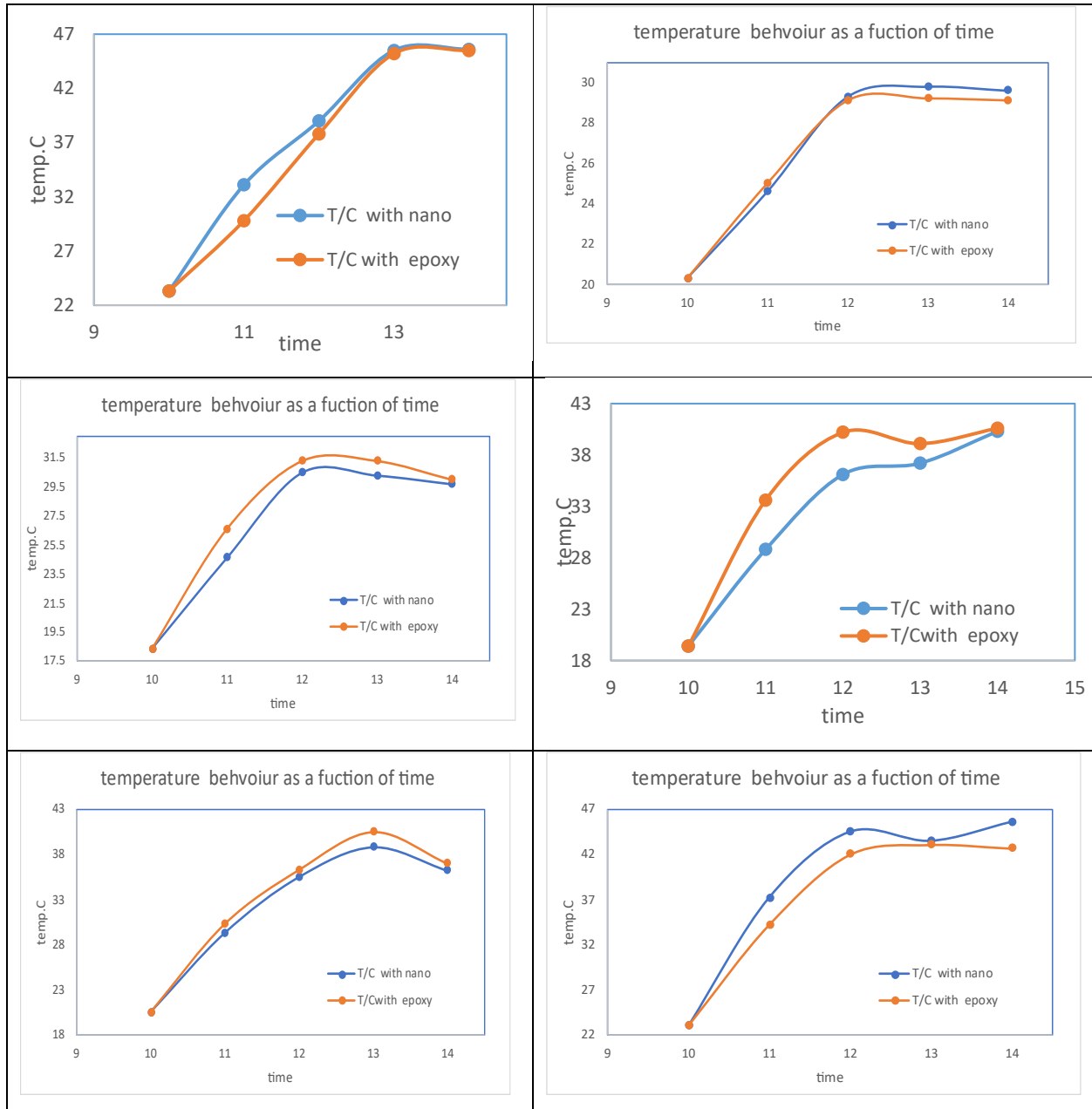
Nanomaterials have become a cornerstone of scientific development in thermal and energy applications due to their unique optical, thermal, and radiative properties, which can strongly influence heat transfer processes in solar systems [1], [2]. In solar thermal applications, surface coatings play a crucial role in governing solar absorption, reflectance, and thermal emission, all of which determine system efficiency under outdoor solar irradiance [3], [4]. Aluminum oxide ( $\text{Al}_2\text{O}_3$ ) nanoparticles are known for their high thermal conductivity and relatively high infrared emissivity, making them promising candidates for enhancing heat transfer performance in polymeric nanocoating [2], [5]. Titanium dioxide ( $\text{TiO}_2$ ) nanoparticles contribute to improved solar stability and spectral selectivity due to their wavelength-dependent reflectivity [6]. When incorporated into an epoxy matrix, these nanofillers can modify both conductive and radiative heat transfer, enhancing overall heat management in thermal surfaces [1], [4]. Recent research has shown that nanocoating and nanofluids can influence thermal performance by altering surface temperatures and heat transfer characteristics. For example,  $\text{Al}_2\text{O}_3$  nanocomposites have been applied in self-cooling photovoltaic systems, resulting in significant temperature reduction and improved energy efficiency under high irradiance conditions [11]. This demonstrates the dual role of  $\text{Al}_2\text{O}_3$ : enhancing heat absorption while potentially increasing radiative losses at elevated surface temperatures. Hybrid systems combining  $\text{Al}_2\text{O}_3$  and  $\text{TiO}_2$  have also shown improved heat transfer performance in outdoor solar applications [10]. Despite these advances, the interplay between heat absorption and radiative heat loss in nanocoated surfaces under realistic outdoor conditions remains a critical challenge. Increased emissivity from nanomaterials can result in higher radiative heat losses, reducing the net heat transferred to a working fluid or surface layer [1],[4]. Understanding this balance is therefore essential for designing efficient nanocoating for solar thermal systems. This study experimentally investigates the thermal performance of cooling radiators coated with an epoxy- $\text{Al}_2\text{O}_3/\text{TiO}_2$  nanocomposite compared with conventional epoxy coatings under direct sunlight in Baghdad. By measuring surface and outlet water temperatures as functions of solar irradiance and time, and by estimating relative emissivity using Stefan-Boltzmann analysis, this work provides new insights into how nanocoating influence heat absorption and radiative heat loss in solar thermal applications.

## Method

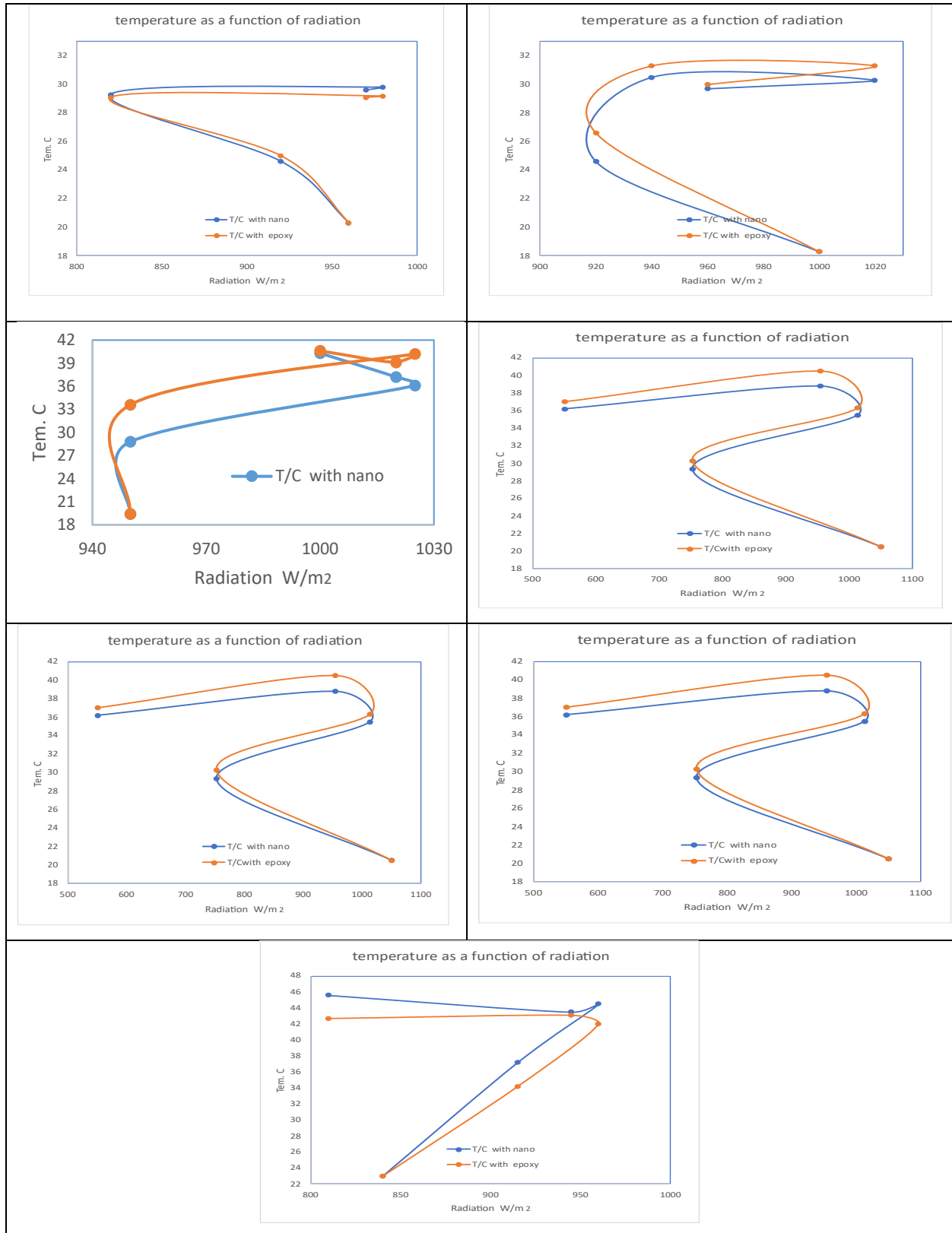
In this experiment, a high-precision balance accurate to three decimal places was used to measure the quantities of the materials included in the preparation of the nanocoating mixture. The mixture consisted of (5%) titanium dioxide ( $\text{TiO}_2$ ) and (15%) aluminum oxide ( $\text{Al}_2\text{O}_3$ ) combined with (80%) epoxy resin. These components were mixed in a 250 ml beaker using a spatula for 15 minutes at room temperature to ensure a homogeneous blend. The aluminum oxide and titanium dioxide nanoparticles were weighed using high-precision digital balances. Different weight ratios were tested to assess performance variations, The prepared nanocomposite was then applied to coat the surface of a car radiator dimension  $50 \times 30$  cm. A second radiator was coated with pure epoxy only, which was chosen as the base material for its excellent adhesion, chemical resistance, and structural durability. Both radiators were left to dry for 48 hours before measuring the temperature of water inside it . After drying, both models were filled with equal amounts of water, and a thermometer was attached to each radiator to monitor temperature changes. where the radiators were positioned at a 30-degree angle facing the sun, and water temperatures were recorded hourly from 10:00 AM to 2:00 PM, to observe thermal behavior and heat transfer over time for each one in the same time.

## Results

The results shows the effect of nanocoating with (5%) titanium dioxide ( $\text{TiO}_2$ ), (15%) aluminum oxide ( $\text{Al}_2\text{O}_3$ ) with (80%) epoxy resin compared with the use of epoxy only, as the results showed that the nano particles epoxy coating have different behaviors as a function of the solar radiation, where the possibility of reducing with the absorption of the highest heat appeared in case the solar beam is less than  $950 \text{ W/m}^2$ , while the same coating showed a different behavior, with increase in emissivity and reducing heat absorption with an increase in the beam to more than  $950 \text{ W/m}^2$  and up to  $1107 \text{ W/m}^2$  . the following tables and figures explain this behavior during February and March.



**Figure 1:** Temperature of water in coated radiator (epoxy with and without nanocomposite) as a function of time.



**Figure 2:** Temperature of water in coated radiator as a function of solar radiation

**Table 1:** water temperature in coated radiator with nanocomposite and epoxy in February

TIME	Ambient Temp. /C	Temp. of input Water /C	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	18	20.3	20.3	20.3	960w/m <sup>2</sup>
11:00	20		24.6	25	920w/m <sup>2</sup>
12:00	21		29.3	29.1	820w/m <sup>2</sup>
1:00	21		29.8	29.2	980w/m <sup>2</sup>
2:00	21		29.6	29.1	970 w/m <sup>2</sup>

**Table 2:** water temperature in coated radiator with nanocomposite and epoxy in February

TIME	Ambient Temp. /C	Temp. of input Water /C	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	18	18.3	18.3	18.3	1000w/m <sup>2</sup>
11:00	20		24.6	26.6	920w/m <sup>2</sup>
12:00	21		30.5	31.3	940w/m <sup>2</sup>
1:00	21		30.3	31.3	1020w/m <sup>2</sup>
2:00	22		29.7	30	960 w/m <sup>2</sup>

**Table 3:** water temperature in coated radiator with nanocomposite and epoxy in March

TIME	Ambient Temp. /C	Temp. of input Water /C	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	20	19.4	19.4	19.4	950w/m <sup>2</sup>
11:00	23		28.8	33.6	950w/m <sup>2</sup>
12:00	25		36.1	40.2	1025w/m <sup>2</sup>
1:00	25		37.2	39.1	1020w/m <sup>2</sup>
2:00	26		40.3	40.6	1000 w/m <sup>2</sup>

**Table 4:** water temperature in coated radiator with nanocomposite and epoxy in March

TIME	Ambient Temp. /C	Temp. of input Water /C	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	27	23.5	23.5	23.5	1005
11:00	28		37.6	38.3	1035
12:00	30		43.5	45	1061
1:00	30		43.5	44.5	1107
2:00	31		42.2	43	914

**Table 5:** water temperature in coated radiator with nanocomposite and epoxy in March

TIME	Ambient Temp. /C	Temp. of input Water /C	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	28	23	23	23	840
11:00	30		37.2	34.2	915
12:00	31		44.5	42	960
1:00	33		43.5	43.1	945
2:00	33		45.6	42.7	810

**Table 6:** Surface temperature of nanocoated and epoxy-coated radiator under different solar radiation intensities

TIME	Temp. of coating with epoxy	Temp. of coating with epoxy and nano	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	24	24	23	23	840
11:00	37.9	39	37.2	34.2	915
12:00	45.8	46.4	44.5	42	960
1:00	45.1	45.9	43.5	43.1	945
2:00	43.9	45.2	45.6	42.7	810

**Table 7:** Surface temperature of nanocoated and epoxy-coated radiator under different solar radiation intensities

TIME	Temp. of coating with epoxy	Temp. of coating with epoxy and nano	Temp. of Water OUT With nano coated /C	Temp. of Water OUT with epoxy coated/C	Solar radiation intensity w/m <sup>2</sup>
10:00	22.7	22.8	20.3	20.3	960w/m <sup>2</sup>
11:00	27.4	27.9	24.6	25	920w/m <sup>2</sup>
12:00	31.9	32.7	29.3	29.1	820w/m <sup>2</sup>
1:00	32	33.1	29.8	29.2	980w/m <sup>2</sup>
2:00	30.9	32.4	29.6	29.1	970 w/m <sup>2</sup>

**Table 8:** the adhesive force of coating with epoxy and nanocomposite Al<sub>2</sub>O<sub>3</sub> +TiO<sub>2</sub>

Coating material	Adhesive force (PSI)
Al <sub>2</sub> O <sub>3</sub> +TiO <sub>2</sub> and epoxy	43 PSI
epoxy	39 PSI

The results above show that the nano-enhanced coating increases the surface temperature of the irradiant by approximately 0.5 to 1.5°C under similar solar irradiance conditions. This is due to the increased absorption coefficient ( $\alpha$ ) of the nano-coated surface, which allows for more efficient absorption of the incident solar radiation. The surface heat behavior conforms to the Stefan-Boltzmann law, which relates the radiation emitted from a surface to its absolute temperature and emissivity, according to the following equation:

$$P = \varepsilon \rho T^4$$

Where P is radiant heat power,  $\varepsilon$  is the emissivity and  $\rho$  is Stefan-Boltzmann constant ( $5.67 \times 10^{-8}$  W.m<sup>-2</sup>K<sup>-4</sup>) and T is the temperature Slightly higher surface temperatures in nano-coated tubes indicate a significant improvement in both absorption and emissivity, thus enhancing thermal radiation from the surface. This will lead to increase in temperature of water inside the radiator

coated with epoxy and nanocomposite as compare with epoxy only. This indicates that the enhanced surface temperature does not lead to excessive heat loss; rather, it facilitates more efficient convective heat transfer to the water. The slight lag between surface and water temperature reflects the thermal inertia of the system, demonstrating that the nano-coating effectively improves solar heat capture while maintaining stable water heating. These experimental results confirm the theoretical relationship between surface properties and thermal behavior:

- Higher absorptivity ( $\alpha$ ) enhances solar energy absorption, increasing surface temperature.
- Higher emissivity ( $\epsilon$ ) contributes to more efficient radiative heat transfer, preventing surface overheating while maintaining energy transfer to the fluid.
- The nano-coating slightly increases both  $\alpha$  and  $\epsilon$ , resulting in enhanced energy capture without compromising outlet water stability.

In addition, Surface temperatures closely follow the variations in solar radiation intensity, with peaks around 12:00–13:00. Nano-coated surfaces consistently maintain higher temperatures than epoxy surfaces under equivalent solar intensities, reflecting the combined effect of increased absorptivity and emissivity.

## Conclusion

This study aimed to investigate and compare the thermal performance of nano plating systems and epoxy-based composites incorporating aluminum oxide ( $\text{Al}_2\text{O}_3$ ) and titanium dioxide ( $\text{TiO}_2$ ) nanoparticles under varying solar radiation conditions. Over the experimental period from 1/03/2025 to 30/04/2025, daily measurements were conducted to observe outlet water temperatures, solar radiation intensity, and environmental temperatures at different times of the day. The results consistently demonstrated that both nanoplating and epoxy composites possess enhanced heat absorption and retention properties compared to traditional materials. However, epoxy-based composites generally exhibited superior thermal performance under most test conditions, especially during periods of high solar irradiance. The epoxy system maintained higher outlet temperatures in the majority of the trials, indicating better thermal conductivity and stability, particularly under fluctuating or reduced radiation intensities. One notable exception occurred on 07/04/2025, when nanoplating showed a higher outlet temperature at peak solar exposure. This

deviation may be attributed to environmental variations, fluid flow behavior, or nanoparticle dynamics that warrant further investigation. Overall, the study affirms the practical potential of incorporating Al<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> nanoparticles into cooling systems. Epoxy-based composites, in particular, offer promising applications in thermal management for renewable energy systems, electronics, and infrastructure exposed to high thermal loads.

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