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Thermal Performance Investigation Of Solar Desalination Systems With Novel Nano-Coated Absorber Trays

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Nano-structured and cost-effective coatings are mandatory in absorptive trays of solar desalination systems so as to have improved absorption of incident solar radiation, enhanced heat transfer to the working fluid and higher thermal performance of the thermal system. In the present investigation, the nano-sized carbon, nano-sized nickel oxide and conventional absorptive solution were mixed in different proportions. Subsequently, the developed coatings were deposited on solar absorber trays through spray coating method. The present research focuses on the preparation, characterization, and thermal evaluation of nano-sized graphite and nickel oxide composite absorber coatings for the solar desalination systems. Nano-sized graphite and NiO powders were mixed in three composition (60:40, 70:30, and 80:20) and incorporated into a conventional absorptive solution, which was deposited onto aluminium substrates through a spray-coating technique. Structural analysis using X-ray diffraction (XRD) confirmed the formation of nanoscale crystallites in the coated layers. Thermal durability testing at 175 °C indicated that the coatings exhibited neither peeling nor fading, demonstrating their stability under operational conditions. Outdoor thermal evaluation revealed that the absorber coated with an 80% graphite and 20% NiO composition achieved the highest surface temperature compared to other ratios under varying meteorological conditions. The findings confirm that nano-sized graphite–NiO composite coatings are energy-efficient, cost-effective, and thermally durable and it could be integrated into solar collectors and solar desalination systems to enhance overall thermal performance.

Keywords: Solar absorbers- nano sized graphite and Nickel Oxide based coating-Preparation -Characterization-Thermal durability-Thermal enhancement on absorbers.

INTRODUCTION

Solar still or solar desalination is a device to desalinate impure water like brackish or saline water. It a simple device to get potable/fresh distilled water from impure water, using solar energy as fuel, for its various applications in domestic, industrial and academic sectors. The balance between the demand and supply of fresh water can be achieved not only by enhancing the thermal performance of existing desalination systems but also by developing and implementing novel systems across various application sectors. The solar absorber serves as the central component of any solar thermal system. Its primary function is to absorb incident solar radiation [1], while its secondary function is to transfer the absorbed energy to a working fluid through conduction [2]. It is pertinent to note that nano-composite coated absorbers exhibit increased solar radiation absorption and improved heat transfer to the working fluid. In this context, the present research work focused on: (i) the preparation of nano-composite coated solar absorbers, (ii) the characterization of the prepared absorbers, and (iii) the thermal analysis of these absorbers. All objectives were accomplished using standard methodologies, and the corresponding research outcomes are presented in this paper. These outcomes will be beneficial to researchers involved in the preparation and evaluation of the thermal efficacy of eco-friendly solar absorbers. They will also support solar manufacturers in the development of energy-efficient and cost-effective absorber technologies.

MATERIALS AND METHODS

Solar Still

A solar still consists of a transparent cover in a square pyramid shape and the bottom of the basin is painted black or selectively nano coated so as to absorb solar heat effectively. The top of the basin is covered with transparent glass tilt and it is fitted in such a way that the maximum solar radiation can be transmitted in to the still. The edges of the glass are sealed with the basin using rubber gasket so that the entire basin becomes air tight. The out let of the still is connected with a storage container. Necessary provisions have been made to fill the saline water in the still basin. The window provision is given in the basin to clean the basin from inside. The entire assembly is placed on a supporting structure. The dimensions and integral components of the system are provided in Table 1. The schematic diagram of pyramid shaped solar desalination system shown in fig:1.

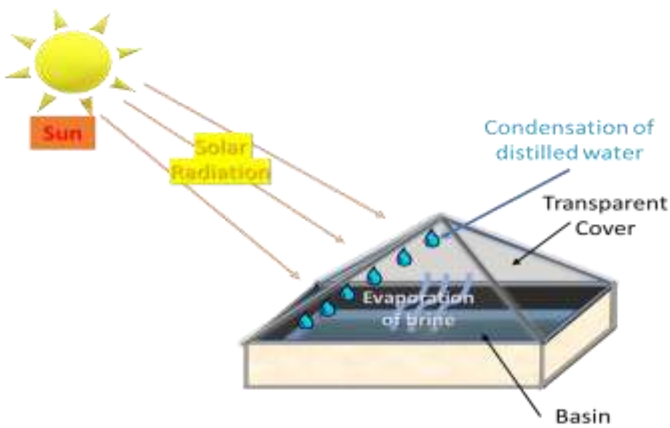

Fig: 1 The schematic diagram of pyramid shaped solar desalination system

Table 1: Dimension and Characteristics of Integral Components

Integral components	Dimensions / Characteristics	
Glass cover	Thickness	4 mm
	Transmissivity	0.84
	Area	1.0 m^2
	Tilt angle	20°
Absorber	Material	Aluminium/ Copper
	Thickness	0.4 mm
	Coating	Graphite and nickel oxide
	Particle size	Nano size
Polystyrene insulation	Thickness	60 mm
	Density	35 kg /m^3
	Thermal conductivity	0.029 W/m °C
Internal reflector (mirror)	Thickness	4 mm
	Area	1.2 m^2
External reflector (mirror)	Thickness	4 mm
	Area	1.0 m^2
External reflector inclination	0° (vertical), 10°, 20°, 30°	

Preparation of Absorptive Coating

In the present research work, nano-sized graphite and metal oxides were commercially procured. Nano-sized graphite and nickel oxide were mixed with different compositions of 60:40, 70:30, and 80:20, respectively. The mixed powders of nano-sized graphite and nickel oxide were thoroughly stirred in a conventional absorptive solution using a mechanical stirrer. The resulting absorptive solution was subsequently used for coating solar substrates [3]. This prepared solution was applied onto pre-cleaned aluminum substrates using a spray-coating technique.

Deposition of Absorptive Coating

During deposition, the spray head was maintained at a distance of 15 cm from the pre-cleaned aluminium substrates. The prepared absorptive solution was sprayed at a rate of 10 $ml \cdot min^{-1}$ onto the substrates, using compressed air as the carrier gas. The coated substrates were visually inspected, and the uniformity of the coatings was confirmed by naked-eye observation [4].

XRD Characterization

X-ray diffraction (XRD), being an ideal technique for assessing the structural characteristics of materials, was employed to analyze the developed absorber samples. The resulting diffractogram provided the 2θ values, interplanar spacing (d values), net intensity, and relative intensity. The crystallite size present in the coating was calculated using the Debye–Scherrer formula, as presented in Equation (1):

$$D=K\lambda/\beta\cos\theta \quad \text{-------- (1)}$$

where D is the crystallite size, K is the correction factor, λ is the wavelength of the X-ray used, β is the full width at half maximum (FWHM) of the observed peaks, and θ is the diffraction angle [5].

Thermal Durability

The prepared nano-composite coated solar absorbers were subjected to thermal durability testing by placing them in a hot air oven at 175 °C for four hours. After heating, the samples were cooled in accordance with Bureau of Indian Standards (BIS) specifications. The thermally tested absorber samples were then examined for any peeling, fading, or deterioration of the coating [6].

Temperature Measurement on Solar Absorbers

For temperature evaluation, the prepared absorber was kept in outdoors for the measurement of temperature on absorber in varied meteorological conditions. The prepared nano-composite coated absorbers were placed outdoors, where their temperatures were recorded under varying meteorological conditions. Influencing parameters, such as incident solar radiation, ambient temperature, and wind speed were also monitored. Throughout the experimental period, the absorber samples were maintained free from dust, shadows, and other external disturbances to ensure accurate measurements [6]. The system was further enhanced by incorporating internal and external mirrors to augment incident solar radiation, along with a specially developed nano-coated absorber to improve solar radiation absorption and thereby enhance overall thermal performance.

RESULTS AND DISCUSSION

The present research focused on the preparation, characterization, and evaluation of the thermal efficacy of nano-sized graphite and nickel oxide coated solar absorbers. The technical specifications of the developed absorbers are provided in Table 2. The outcomes of the characterization studies, the thermal efficacy performance of the absorber and the temperature enhancement in the solar still are presented in Table 3, Table 4 and Table 5, respectively. The solar still effectively captures solar radiation and shows improved thermal performance.

Table 2: Technical specifications of solar absorber

Solar absorber	Materials/Sizes
Material	Aluminum/Copper
Length of each absorber	1 m
Breadth of each absorber	1 m
Area of each absorber	$1m^2$
Thickness of each absorber	0.4 mm

Table 3: Constituents and crystallite sizes

Parameters	Results
Constituents of coating	Nano carbon and Nickel Oxide

Substrate	Aluminum/Copper
Calculated crystallite size	35.33 nm

Table 4: Thermal efficacy of solar absorbers

Time (hrs)	Solar radiation (W/m^2)	Ambient temperature (ºC)	Temperature on solar absorber (ºC)		
			On 60 C:40 NiO coated absorber	On70 C:30NiO coated absorber	On 80C:20NiO coated absorber
11:00	681.4	33.0	53.8	55.0	59.0
11:30	736.5	33.1	57.5	58.5	61.6
12:00	786.1	33.5	53.1	54.4	58.8
12:30	796.5	33.9	50.2	55.1	56.0
13:00	816.4	34.1	47.5	56.0	58.1

Table 5: Temperature enhancements in solar still

Time (Hr)	Solar Radiation (W/m^2)	Ambient Temperature (º C)	Wind Speed (m/s)	Temperature (º C)		
				Glass (º C)	Basin (º C)	Fluid (º C)
10.00	478.3	28.7	0.6	36.9	36.8	36.8
10.30	518.0	29.7	0.7	38.2	38.1	38.0
11.00	768.4	30.1	0.7	39.1	39.1	39.2
11.30	786.5	30.4	0.9	40.7	40.6	40.6
12.00	793.2	31.1	0.7	41.5	41.5	41.5
12.30	785.1	32.5	0.8	46.7	46.6	46.5
13.00	773.2	30.4	0.9	48.8	48.7	48.6
13.30	674.0	30.6	1.2	46.1	46.2	46.2
14.00	678.4	31.5	0.5	46.6	46.7	47.8

In this study, low-cost aluminium was selected as the substrate material for the nano-composite coatings. The length, breadth, and thickness of the substrates were fixed according to standard specifications. These substrates were coated with nano-sized graphite and nickel oxide mixtures in different ratios using a spray-coating method. The resulting nano-composite coated substrates functioned effectively as solar absorbers and were subsequently used for further investigations [7].

XRD characterization was performed on the nano-sized graphite and nickel oxide coated absorbers. The crystallite sizes of the constituents present in the coated layers were calculated from the generated diffractogram using the Debye–Scherrer formula. The XRD pattern of the nano-sized graphite and NiO coated absorber is presented in Figure 1. The calculated crystallite sizes were found to lie within the nano scale range [7].

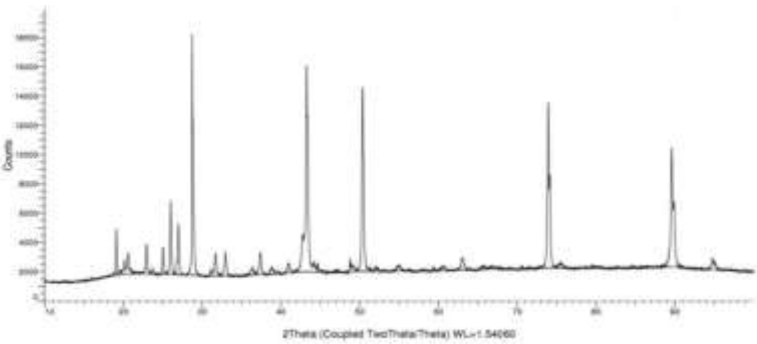

Fig. 1. Diffractogram of the nano-sized graphite and NiO coated absorber.

Thermal durability testing was carried out on the developed nano-composite coated absorbers. The results indicated that there was no peeling or fading of the coatings after exposure to elevated temperatures. Thus, the prepared absorbers demonstrated sufficient stability to withstand both stagnant and operational conditions in solar collectors [8].

For thermal evaluation, the coated absorbers were placed outdoors and exposed to natural weather conditions. During the experimental period, incident solar radiation, ambient temperature, and absorber surface temperature were recorded. Among the tested samples, the absorber coated with a mixture containing 80% nano-sized graphite and 20% NiO exhibited the highest temperature compared to samples with other mixing ratios. Therefore, the absorber with an 80% graphite and 20% NiO composition is identified as the most thermally efficient and is recommended for further applications [9].

CONCLUSION

As the preparation of nano-sized graphite and nickel oxide coated absorbers demonstrates that these energy-efficient, cost-effective, and eco-friendly solar absorbers can be developed for practical applications. Based on the satisfactory thermal durability and thermal efficacy observed in the present investigation, it can be concluded that nano-sized graphite and nickel oxide coated absorbers are suitable for integration into solar collectors and can be effectively used in solar desalination systems to enhance their thermal performance.

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