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Nano carbon and copper oxide coated solar absorbers: Preparation, characterization and assessment of thermal characteristics

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Abstract
Solar absorber coatings are widely used to develop the higher optical and thermal performances of solar thermal devices. Solar absorber is a central component of any solar thermal device. Its optical characteristics can be improved by having coating with nano carbon and copper oxide on the metal based medium. Its thermal characteristics can be studied in the field conditions so as to analyze the impact of those improved optical characteristics of the coated medium. In this connection, the present research was devoted not only to prepare and characterize the nano carbon and copper oxide coated solar absorber but also to analyze the thermal performance of solar thermal collector. It was found that the nano carbon and copper oxide coated solar absorbers could be effectively prepared by using conventional spray coating method. It was also found that the chemical constituents in the coating had the size of 50.12nm. It was as well found that the maximum temperature enhancement of nano coated copper, aluminum, zinc-iron alloy solar absorbers were varied from 39.3 to 50.3 ºC, 39.5 to 50.7 ºC and 38.5 to 48.8 ºC respectively. It could be concluded that nano coated solar absorber would be utilized in solar thermal device with desirable shapes so as to reap better thermal performances.

Keywords: Nano coated solar absorber, preparation, characterization, assessment of thermal characteristics

1. Introduction

Solar absorber is an integral constituent used in solar thermal device. It is heated up due to the incident solar radiation. In addition, it is designed to absorb incident solar radiation. It is also designed to transfer the absorbed energy by means of conduction to any fluid. It is pertinent to mention here that the nano composite coated absorber has increased absorption of solar radiation and enhanced heat transfer to working fluid [3]. In this connection, it is essential to prepare and characterize the nano coated solar absorber. It is also essential to analyze the thermal performance of nano composite coated solar absorber. By considering gaps in the research reviews, the present research was devoted to materialize the objectives such as i) Preparation of nano composite coated solar absorber by coating with nano carbon and copper oxide mixed solar absorptive solution on metal substrate ii) Characterization of chemical constituents mixed in solar absorptive solution and iii) Assessment of thermal characteristics of solar absorbers in field conditions. The standard chemicals, materials and components were used for the preparation of nano based solar absorbers. The standard methodology, test methods and test setups were used for the testing of components and also solar absorbers and the research outcomes of the present research work have been recorded in this research paper.

2. Materials and Methods

2.1 Preparation of nano composite coated solar absorbers

Nano carbon and copper oxide were commercially procured. The commercially procured nano carbon and copper oxide were mixed in suitable mass proportions. They were subsequently mixed in solar emulsion that has been commonly used for black coating on solar absorbers. The mixed nano carbon and copper oxide was stirred thoroughly in the solar emulsion by using the mechanical stirrer.

The copper, aluminium and zinc-iron alloy metal plates were pre-cleaned and it was spray coated with the nano carbon and copper oxide mixed absorptive solution.

The spray rate was fixed to be 10 ml/ minute with compressed air as carrier gas. The distance between the spray head and the metal plates were kept to be 15 cm during the spray coating on metal plate. The developed coating on absorber plates were checked visually and the observations were noted [5].

2.2 Characterisation of nano constituents

The mixed powder of nano carbon and copper oxide in suitable proportions was characterized [2] by using XRD (X-ray Diffractometer) (X' Pert Pro-P Analytic with 15KVA UPS support ID SSD160 detector and Cu-Kα radiation at the wavelength range of 1.541 A°) and the characterisation outcomes have been presented. By the generated XRD diffractrogram, the crystallite size in the coating on heat transfer medium was calculated by using the Debye-Scherrer formula:

$$D = k\lambda/\beta \cos\theta \qquad (1)$$

Where, D is crystallite size, K is correction factor, λ is wavelength of X-ray used, β is the FWHM of the observed peaks and θ is the diffraction angle.

2.3 Thermal durability and characteristics of the solar absorbers

In order to study the thermal durability of the absorber, the prepared solar absorber was heated in an oven temperature of 175 °C for two hours. After heating, the solar absorber was taken out from the oven and they were cooled at room temperature. The peeling of coating, fading of coating and filtering of coating, if any, in the solar absorber was noticed. It was found that there was no peeling of coating on the solar absorber. It was also found that there was neither fading nor filtering of the coating on the solar absorber.

2.4 Assessment of thermal characteristics of solar absorbers

In the present research the nano carbon and copper oxide coated copper, aluminum and zinc-iron alloy solar absorbers were prepared. The prepared absorbers were kept in outdoor atmosphere. They were kept so as to be free from shadow effects and free from dust effects. During experimentation on solar absorbers, the incident solar radiation, wind speed, ambient temperature, relative humidity and temperature enhancement on solar absorbers were recorded. It is to be noted that the thermal analyses were carried out in clear sunny days. It is also to be noted that the thermal analyses were carried out before, after and at solar noon so as to test the solar absorbers in all meteorological conditions.
The coating efficiency of the solar absorber was calculated by the following equation

$$\eta = \alpha - \frac{\varepsilon\sigma T^4}{cI} \qquad (2)$$

Where:
α is the solar absorptance
ε is the emissivity at the temperature T (in °C)
σ is the Stefan-Boltzmann constant = $5.67.10^{-8}$ Wm^{-2} K^{-4}
c is the degree of concentration (600 °C)
I is the irradiance (1KW/m^2)
η is the coating efficiency of the absorber (%)

3. Results and Discussion

The present research was devoted not only to prepare and characterize solar absorber but also to assess the thermal characteristics of solar absorbers. The photographs of non-coated and coated solar absorbers have been presented in Figure 1 and 2. The temperature variation graphs of non-coated and nano coated absorbers have been presented in Fig 3 to 5. The technical specifications and sizes, the characterisation outcomes with reference to XRD have been presented from Table 1 to 3. The temperature enhancement in noncoated and nano coated absorbers and generated thermal profile of non-coated and nano coated absorbers have been presented in Table 4 to 7.

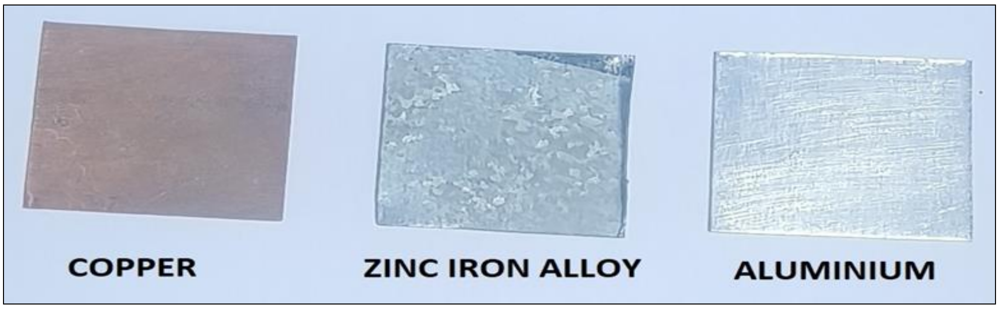

Fig 1: Non-coated solar absorbers

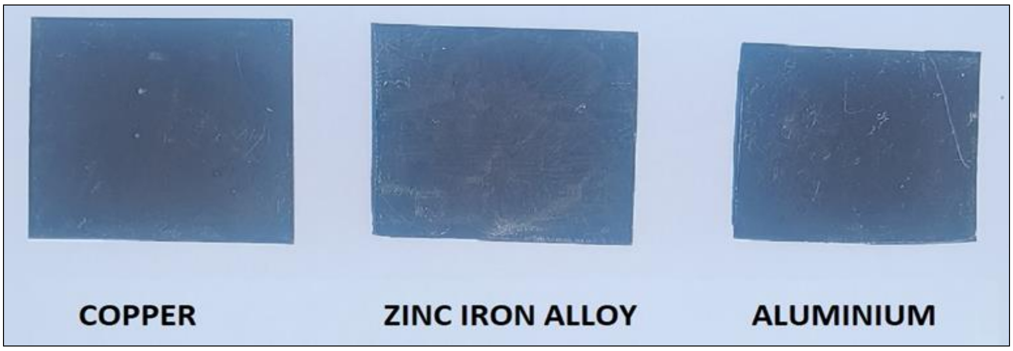

Fig 2: Nano carbon and copper oxide coated solar absorbers

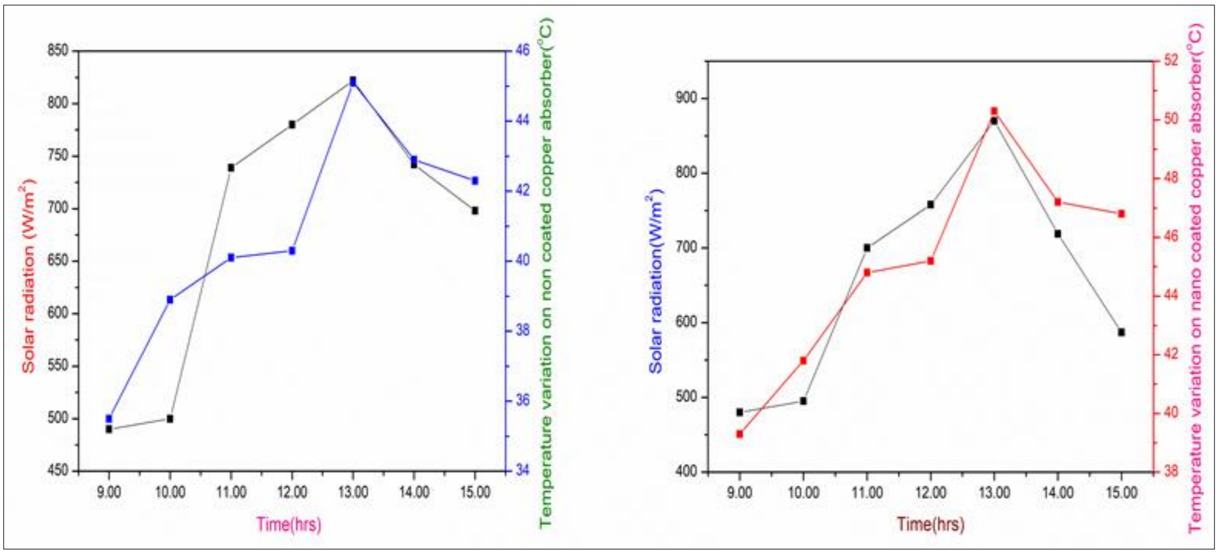

Fig 3: Temperature variation on non-coated and nano coated Copper absorber

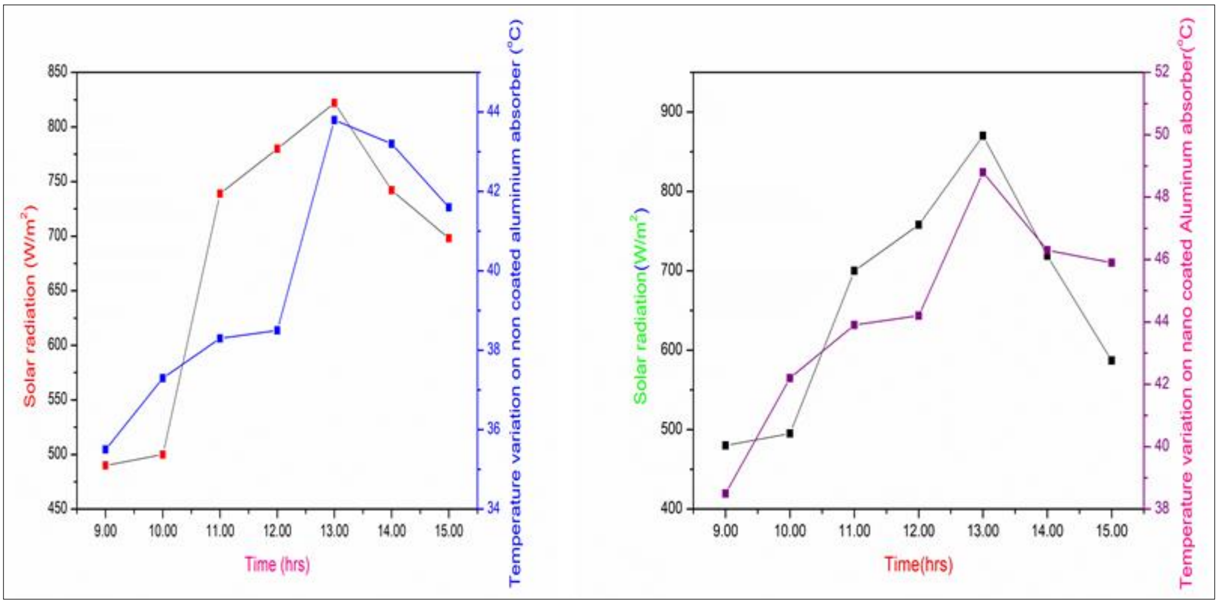

Fig 4: Temperature variation on non-coated and nano coated Aluminium absorber

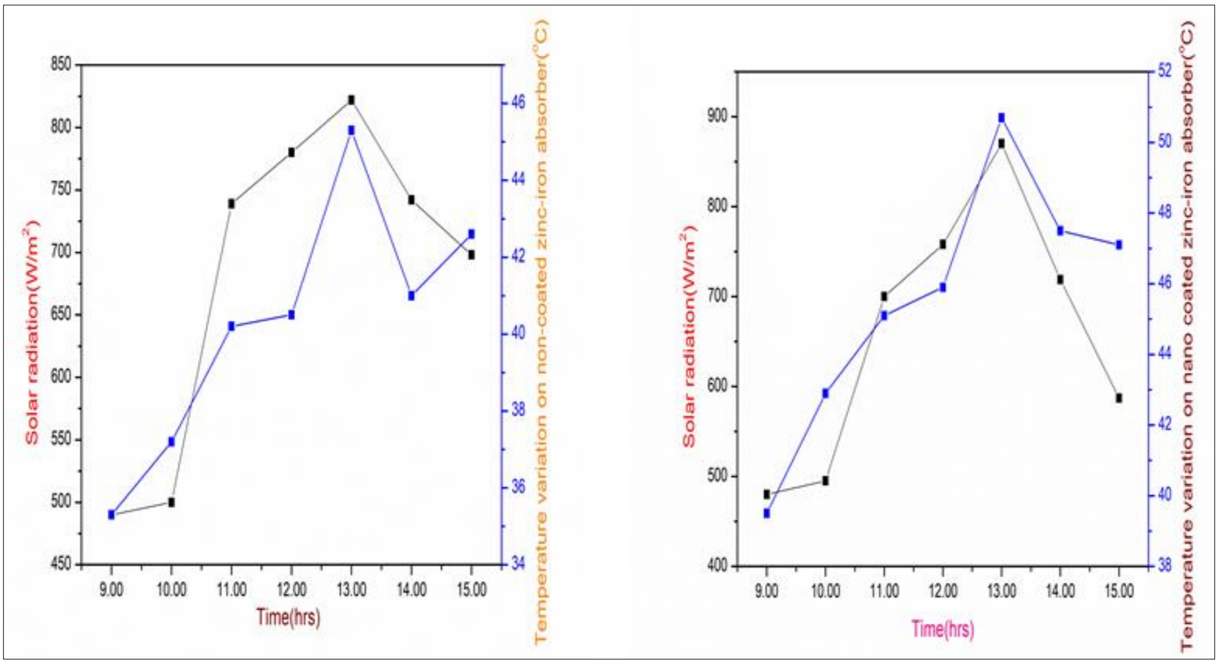

Fig 5: Temperature variation on non-coated and nano coated Zinc-iron alloy absorber

Table 1: Technical specifications and sizes of solar absorbers

Absorber materials	Length (cm)	Breadth (cm)	Thickness (mm)	Surface area (cm^2)
Copper	5.0	5.0	0.50	25.0
Aluminum	5.0	5.0	0.50	25.0
Zinc-iron alloy	5.0	5	0.50	25.0

Table 2: Results of XRD analysis on nano carbon powder

Angle (θ)	D Value (A^0)	Relative intensity (%)
26.6812	3.33839	100.0
24.8739	3.57671	24.56
20.9141	4.24410	22.18

Table 3: Estimated crystallite sizes

Parameter	Value
Interplanar spacing (Å)	3.33839
FWHM (2θ)	0.1632
Crystallite size(nm)	50.12

Table 4: Temperature enhancement on non-coated absorbers

Time (^{h}rs)	Solar radiation (Wm^{-2})	Ambient temperature (°C)	Wind speed (ms^{-1})	Temperature enhancement (°C)		
				Copper	Aluminium	Zinc-Iron alloy
09.00	490	36.0	0.1	35.5	35.3	35.5
10.00	500	41.3	0.1	38.9	37.2	37.3
11.00	739	44.5	1.3	40.1	40.2	38.3
12.00	780	43.7	1.7	40.3	40.5	38.5
13.00	822	44.1	0.1	45.1	45.3	43.8
14.00	742	44.1	0.7	42.9	41.0	43.2
15.00	698	42.1	0.2	42.3	42.6	41.6

Table 5: Temperature enhancement on nano composite coated absorbers

Time (^{h}rs)	Solar radiation (Wm^{-2})	Ambient temperature (°C)	Wind speed (ms^{-1})	Temperature enhancement (°C)		
				Copper	Aluminium	Zinc-Iron alloy
09.00	480	36.2	0.1	39.5	39.3	38.5
10.00	495	40.9	1.2	42.9	41.8	42.2
11.00	700	44.6	1.0	45.1	44.8	43.9
12.00	758	43.8	1.2	45.9	45.2	44.2
13.00	870	43.3	0.1	50.7	50.3	48.8
14.00	719	44.5	0.9	47.5	47.2	46.3
15.00	587	42.9	0.4	47.1	46.8	45.9

Table 6: Thermal profile of non-coated solar absorbers

Solar radiation (Wm^{-2})	Temperature enhancement on solar absorbers (°C)					
	Copper		Aluminium		Zinc-iron alloy	
	Min	Max	Min	Max	Min	Max
< 500	35.5	38.9	35.3	37.3	35.5	37.2
500-700	35.5	42.3	35.3	42.6	35.5	41.6
> 700	40.1	45.1	40.2	45.3	38.3	43.8

Table 7: Thermal profile of nano composite coated solar absorbers

Solar radiation (Wm^{-2})	Temperature enhancement on solar absorbers (°C)					
	Copper		Aluminium		Zinc-iron alloy	
	Min	Max	Min	Max	Min	Max
< 500	39.5	42.9	39.5	41.8	38.5	42.2
500-700	45.1	47.1	44.8	46.8	43.9	45.9
> 700	45.9	50.7	45.2	50.3	44.2	48.8

In the present research, the copper, aluminum and zinc-iron alloy substrates were commercially procured. They were cleaned and rubbed with special paper so as to produce the rough surface. Their sizes were optimally fixed as per standard specifications. The nano carbon and copper oxide coating were deposited on copper, aluminum, zinc-iron alloy substrates and the nano structured solar absorbers were prepared [10]. The thermal durability test on the developed solar absorber was conducted by adopting standard procedure and it was found to be acceptable [1].

Subsequently, the mixed powder was characterized through XRD. The crystallite size of the mixed powder was calculated from the generated diffractogram and its magnitude was found to be in nano ranges (50.12nm) [3].

In the present research, the thermal analyses showed that the temperature enhancement on non-coated copper solar absorber was varied from 35.5 to 45.1 °C. It was also showed that temperature enhancement on non-coated aluminum solar absorber was varied from 35.3 to 45.3 °C. It was as well showed that temperature enhancement on non-coated zinc-iron alloy solar absorber was varied from 35.5 to 43.8 °C. At the same time, the temperature enhancement on nano-coated copper solar absorber was varied from 39.3 to 50.3 °C. It was also showed that temperature enhancement on nano-coated aluminum solar absorber was varied from 39.5 to 50.7 °C. It was as well showed that temperature enhancement on nano-coated zinc-iron alloy solar absorber was varied from 38.5 to 48.8 °C. Subsequently, the average coating efficiency of the nano coated copper, aluminium and zinc-iron alloy solar absorbers were found to be 84.5, 84.9, and 83.7% respectively.

In the present research, the nano carbon was selected so as to have effective absorption of solar radiation. The copper oxide was selected so as to reduce thermal emittance from the hot solar absorber [6]. The spray coating method was selected so as to have uniform coating on the solar absorber with the surface area of 25cm^2. All the results related to thermal analyses on solar absorbers could be correlated with materials of solar absorbers, material characteristics and sizes of solar absorbers. They could be also correlated with the presence of nano carbon and copper oxide, usage of solar emulsion liquid binder and method of coating on solar absorbers. All the results related to thermal analyses on solar absorbers could be attributed with incident solar radiation, influence of meteorological conditions and impact of climate conditions during the experimental tenure. They could also be attributed to coatings on solar absorbers, absorptivity of coatings on absorber and heat transfer property of materials used as solar absorbers [4, 7].

4. Conclusion

On the basis of generated database of the present research work, it could be concluded that the prepared solar absorbers with nano composite coating would be utilized in solar thermal devices due to their optical absorptivity, thermal durability and thermal efficacy in field conditions.

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