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Preparation and Characterization of Nano-Carbon and Aluminium Oxide Based Fins and their Applications in Solar Water Heating Collector

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ABSTRACT

This applied research deals with not only the preparation and characterization of nano-structured solar fins but also the evaluation of efficiency of solar collector integrated with the nano-structured fins. In this connection, fins in standard sizes were procured and the nano- structured coating with the composition of carbon and aluminiumoxide was deposited on them. The coatings on fins were characterized through X-ray diffraction (XRD) and scanning electron microscopy(SEM) and the fins were subjected to thermal analysis. The coated fins were integrated in a solar collector and thermal performances of the collector were experimentally found for a set of inlet temperatures of working fluid. The overall thermal performance of the collector was calculated through a graph that was generated as per standard specifications. It was found that the sizes of the grains in the coating were in nano range with orthorhombic structure. It was also found that the temperature enhancement on the solar fins with carbon and aluminium coating of 75:25compositions in stagnant conditions had the maximum value 109.1℃. While the maximum instantaneous thermal performance was found to be73%, the overall thermal performance of the solar collector was found to be70%.On the basis of the generated results in the present investigation, it could be concluded that nano –so as to reap enhanced thermal performances.

1. Introduction

Solar collector is a central device in solar thermal gadgets and the research literature reveals that the flat plate collector is the widely used solar collector for fluid heating applications in developing countries[1]. It is reported that the major integral component of flat plate collector is fin and the characteristics of this integral component mainly determine the thermal performances of solar collector[2].It is also reported that nano-structured coating on fins can enhance the absorption efficacy of fins and so the thermal performances of solar collector can be increased[3]. In this connection, it is essential not only to prepare and deposit nano-composite coating on fins but also to characterize the coating on fins. It is also essential not only to measure thermal enhancement on the developed solar fins in outdoor conditions but also to estimate the thermal performances of solar collector integrated with nano-structured fins. In these perspectives, the present investigation was devoted for the (i) preparation of absorptive coating with the composition of nano-carbon and aluminum oxide (ii) deposition of the prepared coating on solar fins by spray coating method (iii) characterization of the deposited coating and (iv) measurement of thermal enhancement on nano-structured solar fins and (v) estimation of instantaneous and overall thermal performances of solar collector integrated with nano-structured fins. While standard methods were adopted for the preparation and deposition of nano-carbon and Al_2O_3based absorptive coatings, standard techniques were used for the characterization of coatings on the developed fins[4].

The thermal enhancements on fins in outdoor atmospheres were measured and the thermal performances of solar collector that was integrated with the nano-structured fins were estimated by adhering BIS specifications[5]. As the present research was started from the preparation of nano-structured solar fins and finished with their applications in solar collectors, the outcomes of this complete and applied research would be beneficial to researchers, manufactures and end users worldwide.

2. Materials and Method

2.1. Preparation and deposition of nano-carbon based absorptive coating on solar fins.

In the present study, carbon blocks were commercially procured. By using ball milling method, the carbon blocks were made into nano-sized carbon powder[6]. The nano-sized Al_2O_3 was commercially procured and it was mixed with prepared nano carbon at different proportions. The conventional absorptive solution that is commonly used by the manufacturers for coating on absorbers in solar collectors was procured from a solar industry. The nano-sized carbon and Al_2O_3 in different ratios such as 25:75, 50:50 and 75:25 on weight basis was stirred thoroughly by a mechanical stirrer in the conventional absorptive solution. The resultant absorptive solution with different carbon and Al_2O_3 proportions was used for coating on fins. This nano-composite based absorptive solution was sprayed at a spray rate of 10ml/minute on the cleaned metal fins by using the compressed air as carrier gas[7]. The distance between spray head and the fins was kept at approximately 15cm. After the coating was done, visual

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inspect Ion was carried out and the uniformity in the coating was confirmed[8].

2.2. Characterization of coating on solar fins

The XRD is one of the essential techniques to investigate the structural aspects of the coated materials[9] and the structural characterization with reference to XRD was carried out on the fin sample. The particle size in the coating was calculated by using the Debye Scherrer formula

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

Where D is particle size, x is correction factor, θ is angle of diffraction, λ is wavelength of X-ray used and β is the FWHM of the observed peaks [9].

By substituting the parameters in the equation1, the particle size was calculated in the present study. The scanning electron microscope (SEM) is a technique used for the study of the morphology[10] and so the developed fin sample was characterized through SEM and its morphology was studied.

2.3.Thermal studies on solar fins and collector

The prepared nano-structured fins were heated in an oven at a temperature of 175°C for four hours continuously[11]. After heating, the fins were taken out and they were cooled at room temperatures. The cooled fins were inspected visually for observing damages, if any.

The prepared fins coated with different carbon and Al_2O_3 proportions were kept in outdoors in such away that there would be no fall of dusts, shadows and other influencing materials on them. The parameters such as incident solar radiation, ambient temperature and wind speed along with the temperature on the fins were monitored during the experiment[12]. The monitored parameters have been reported in this research paper.

For developing a solar water heating collector, an aluminium absorber assembly of two square meter size was commercially procured. This assembly had eight non-coated fins, eight non-coated risers and two non-coated headers. The fins, risers and headers were coated with nano-carbon and Al_2O_3 mixed solution by spray coating technique. With the absorber assembly, the major integral components such as glass cover and insulation were integrated. While the used glass cover was toughened glass cover, the used insulation material was rock wool. These major integral components were fixed by using channel sections, angle sections, bottom sheet, gaskets and grommets. The developed collector was tested on the basis of the test specifications prescribed by Bureau of Indian Standards [5,12].

The solar collector was mounted outdoors at an angle of 30° from horizontal so as to have a normal incidence of solar radiation and it was oriented in fixed position facing equator. The solar collector was located in such way that shadows would not be cost on the collecting device at anytime during the test period and there would be no significant solar radiation reflected on to it by surrounding buildings or surfaces during the tests. Surfaces such as large expanse of glass, metal or water, or having high temperature namely chimneys, cooling towers and hot exhausts were avoided from the field view of the collector[13].

In the present investigation, instantaneous performance, which would be the measure to find how effectively the incident energy on the solar collector would be transferred to the water flowing through the collector, was experimentally found[14]. In this connection, the test conditions such as (a) total solar irradiance at the plane of collector aperture should not be less than 700 Wm-2 (b) average value of the surrounding air speed should be in between 0 ms-1 and 5 ms-1 and (c) fluid flow rate should be 0.02 Kg per sec per square meter of collector gross area were maintained for conducting the instantaneous performance test [5,11].

The instantaneous performance of the developed solar collector was calculated by the equation 2.

$$\eta = \dot{m}\, Cp\,(To - Ti) / Ag\, I(t) \qquad (2)$$

where $\dot{m}$ is mass flow rate in Kg sec^{-1}, C_p is specific heat capacity in $J^{-1}Kg^{-1}K^{-1}$, Ti is inlet temperature in ℃ , T_o is outlet temperature in ℃ , A_g is gross area of the collector in m^2 and I(t) is solar radiation in Wm^{-2} [14]. The parameters such as gross area (A_g) and aperture area, solar radiation I (t), surrounding air speed (ω), temperature at the collector inlet (Ti), temperature at the collector outlet (To) and mass flow rate of the air ($\dot{m}$) were noted during the experimental tenure. All these values were substituted in the thermal performance formula and the instantaneous performances of solar collector were calculated [15]. In the present research, the collector was specifically tested for the inlet water temperatures of 30℃, 40℃, 50℃ and 60℃ and the instantaneous thermal performances of the developed collector were calculated. The values of instantaneous thermal performances were plotted against the parameter (Ti-Ta) / I (t) and a straight line with a negative slope was obtained. While the y intercept could provide the value of the overall thermal performance, the slope would be the product of heat removal factor and overall thermal loss coefficient of the collector [16].

Table 1.Technical specifications of solar collector.

Components	Specification
Glass cover	
Material	Toughened
Thickness	4.00mm
Transmittance	82%
Surface area	$2m^2$
Fin	
Material	Aluminium
Coating	Nano composite
Number of fins	8
Surface area	$2m^2$
Insulation Material	
Material	Rockwool
Thickness(side)	25mm
Thickness (bottom)	50mm
Surface area	$2m^2$
Solar collector	
Length	2010mm
Breadth	1010mm
Height	110mm

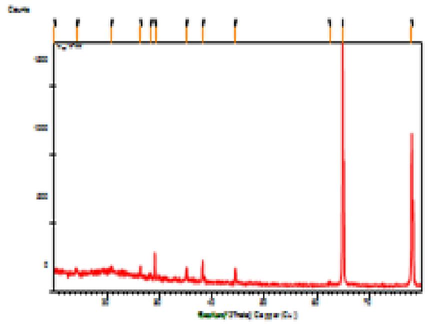

Figure 1. Diffractogram of carbon andAl_2O_3

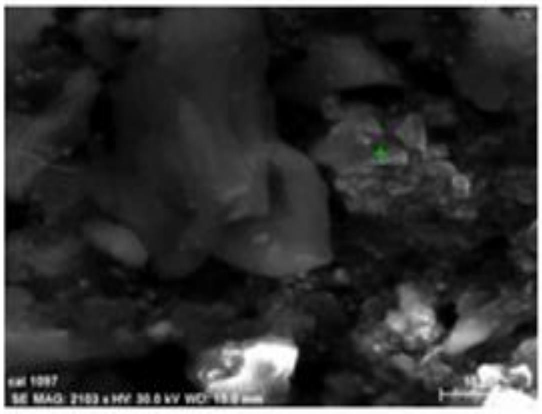

Figure 2. SEM image of carbon and Al2O3.

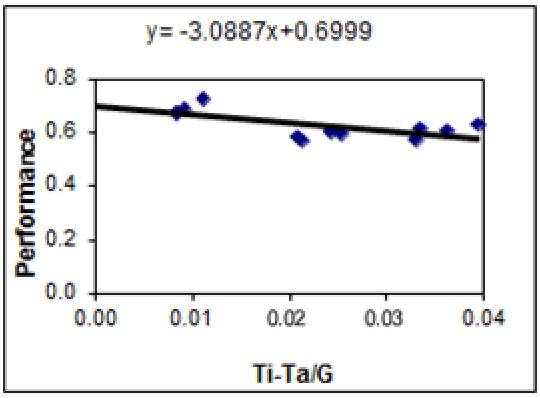

Figure 3. Estimation of performance.

3. Result and Discussion

In the present investigation, solar fins with nano-composite coating were developed. In addition, a solar collector integrated with nano-structured fins was developed. The technical specifications of the developed solar collector have been presented in Table 1.

Three sample fins of sizes 200 mm x 100 mm each were developed. While the first sample was with 25:75 carbon and Al_2O_3 coating, the second sample was with 50:50 carbon and Al_2O_3 coating. The third sample with 75:25 carbon and Al_2O_3 coating. All these sample fins were kept in outdoors during sunshine hours [11]. The temperature enhancements on all these samples were noted and they have been presented in Table 2.

As the sample with 75:25 carbon and Al_2O_3 coating endured higher temperature enhancements than those of other samples, the coating with this composition was deposited on integrated fins (2010 mm x 1010 mm in sizes) of absorber assembly. The temperature enhancements on absorber assembly in stagnant conditions were also noted and they have been presented in Table 3. The coating on absorber assembly was characterized and the outcomes of XRD and SEM have been presented in Figure 1 and Figure 2 respectively.

The developed solar collector with the nano-structured absorber assembly was kept in outdoors for determining its thermal efficiency and necessary parameters such as solar radiation, ambient temperature, wind speed and temperature of working fluid were recorded [17]. The increases in temperature of working fluid along with related meteorological parameters have been presented from Table 4 to Table 7 respectively. The graph for the estimation of overall performance of solar collector was generated and it has been presented in Figure 3.

The measurements on components and collectors were carried out by using calibrated instruments [18]. The thicknesses of the glass cover, absorber sheet, cover foil, bottom sheet, support retaining the glass cover and the channel section of the flat plate collectors were found to be 4.37, 0.02, 0.01, 0.76, 1.20 and 1.60 mm respectively. The diameter of the riser and header were found to be 12.60 and 24.60 mm respectively. The dimensions of the flat plate collector were found to be 2010, 1010 and 110 mm respectively. All these dimensions were found to adhere with the specifications prescribed in Indian Standards [5]. These dimensions of components were selected so as to have simplicity in design, easiness in fabrication and good thermal performance [12].

In the experimental part, the sample solar fins with nano-structured carbon and Al2O3 in 25:75, 50:50 and 75:25 compositions were prepared by adopting spray coating method. All these samples were subjected to thermal durability test [11] and the results of the thermal durability test revealed that there was no discolourisation, blistering and peeling off the nano-structured surface on the fins during the experimental period [5]. The prepared fins were kept in

Table 2.Temperature enhancement on sample fin (200mmx100mm).

Time	Solar radiation Wm^{-2}	Ambient Temperature ℃	Wind Speed ms^{-1}	Temperature on substrate℃			
				Substrate with Conventional coating	Substrate with Carbon and Al_2O_3 (25:75)coating	Substrate with Carbon and Al_2O_3 (50:50) coating	Substrate with Carbon and Al_2O_3 (75:25) coating
10.00	512.4	29.6	0.3	38.0	42.1	42.6	42.9
10.30	631.6	30.2	0.1	38.2	43.0	43.4	44.0
11.00	701.3	30.3	0.1	39.0	44.2	44.5	44.8
11.30	724.6	31.0	0.2	40.4	45.0	45.6	46.1
12.00	769.4	31.3	0.4	41.4	45.3	45.9	46.5
12.30	781.6	31.6	0.2	40.6	45.1	45.4	46.0
13.00	702.7	30.9	0.1	40.4	44.9	45.1	45.7
13.30	680.3	30.6	0.6	39.0	44.0	44.5	44.9
14.00	612.9	30.4	0.3	38.2	42.9	43.9	44.0

Table 3. Temperature enhancements on integrated fins (2010mmx1010mm) in stagnant condition.

Time	Solar radiation Wm^{-2}	Ambient Temperature ℃	Wind speed ms^{-1}	Temperature of working fluid (℃)			Thermal Performance %
				Initial temperature	Final temperature	Enhancement	
11:00	701.3	31.5	2.8	30.0	36.3	6.3	72
11:30	745.3	32.4	2.0	30.0	36.5	6.5	70
12:30	766.6	32.9	2.4	30.0	36.8	6.8	71
13:00	778.3	33.0	2.7	30.0	37.0	7.0	72

Table 5. Estimationofthermalperformance forInletwatertemperatureof40℃.

Time	Solar radiation Wm^{-2}	Ambient Temperature ℃	Wind speed ms^{-1}	Temperature of working fluid(℃)			Thermal performance %
				Initial temperature	Final temperature	Enhancement	
11:00	70 4.1	32.2	3.0	40.0	46.4	6.4	73
11:30	767.4	33.0	2.1	40.0	46.6	6.6	69
12:30	804.3	33.2	2.4	40.0	46.8	6.8	68
13:00	795.3	33.4	2.6	40.0	46.7	6.7	69

Table 6. Estimation of thermal performance for Inlet water temperature of 50℃.

Time	Solar radiation $W^{m^{-2}}$	Ambient Temperature ℃	Wind speed ms^{-1}	Temperature of working fluid(℃)			Thermal performance %
				Initial temperature	Final temperature	Enhancement	
11:00	712.6	32.0	2.9	50.0	55.3	5.3	60
11:30	732.0	32.3	3.2	50.0	55.5	5.5	60
12:30	815.7	32.7	3.7	50.0	55.8	5.8	59
13:00	821.7	32.9	2.5	50.0	56.0	6.0	59

Table 7. Estimationofthermalperformance forInletwatertemperatureof60℃.

Time	Solar Radiation Wm^{-2}	Ambient Temperature ℃	Wind Speed ms^{-1}	Temperature of working fluid (℃)			Thermal performance %
				Initial temperature	Final temperature	Enhancement	
11:00	712.0	31.9	2.1	60.0	65.6	5.6	63
11:30	765.1	32.3	2.3	60.0	65.8	5.8	61
12:30	833.4	32.5	2.8	60.0	66.0	6.0	58
13:00	807.9	33.0	2.5	60.0	66.2	6.2	62

outdoors and the increase in temperature on solar fins was noted in varied meteorological conditions [16]. The first sample (with 25% Al2O3 and 75% carbon based coating) had the temperature that ranged between 42.1 and 45.3℃. While the second sample (with 50% carbon and 50% Al2O3 based coating) had the temperature that varied from 42.6 and 45.9℃, the third sample (with 75% Al2O3 and 25% carbon based coating) had the temperature that ranged between 42.9 and 46.5℃. On the whole, it was perceived that the solar fin with 25% Al2O3 and 75% carbon based coating had the highest temperature in the outdoor conditions. So, the coating of 75:25 carbon and Al2O3 composition was chosen for further applications. It would be worth mentioning here that nano carbon was selected due to its absorption ability, nano sized Al2O3 was selected due to its thermal conductivity with simultaneous benefits of amplified toughness and integrated hardness [19,20].

As an integral part of experimental work, an absorber assembly with non-coated fins, risers and headers was taken. It was spray coated with the selected absorptive solution that contained 75% carbon and 25% Al2O3. The coated absorber assembly was fixed in a collector and the developed collector was mounted on test frame in outdoor conditions. The stagnation condition was maintained in the collector and the stagnant temperatures at the top, middle and bottom points of absorber assembly were measured during the experimental tenure. It was found that the stagnation temperature in solar collector varied from 102.7 to 107.1 ℃. It was also found that the recorded minimum stagnation temperature was 3.2℃ higher than that of the collector with absorber assembly that had conventional coating [21].

The flat plate collector had the major integral components such as glass cover, fin and insulation material [22]. The toughened glass was used as glass cover and it was found to be free from bubbles and rough surfaces. The used toughened glass cover was highly resistant to breakage both from thermal cycling and natural events [23]. The transmittance of the glass cover was found experimentally and it was estimated to be 84% [24]. As aluminium has surface suiility (for having effective coating on the fin surface) and thermal conductivity, an aluminium absorber assembly with integrated fins was procured.

On the procured fins, the carbon and aluminium oxide based nano-composite coating was deposited [10]. The structural characterization of the coating on fin was performed through XRD analysis by using X-ray diffractometer of make XPERT-PRO operating at 50 KV and 30 mA with a normal θ-2θ scanning [23].

The peaks in the Figure 1 were identified to originate from (004) and (271) reflections [JCPDS-file no: 48-1583] and the system was identified as orthorhombic with cell parameters a = 8.536Ao; b = 9.098Ao; c = 5.746Ao. The diffractogram revealed that the coating on fins was mainly composed of nano-carbon and aluminium oxides. By substituting the required values in the Scherrer formula [6] as given in equation 1, it was found that the particle size of the coating on fin was 61.14 nm. The SEM image shown in Figure 2 revealed the presence of crystallized carbon and Al2O3 nano particles in spherical shapes. The rock wool was used as insulation material in the collector. The thermal resistance of insulation material was estimated to be 0.96 m2CW-1. As per the specification of Bureau of Indian Standards, the thermal resistance of rock wool used in solar collector was found to be satisfactory [12]. All these major integral components were integrated by fixing the auxiliaries like channel section, angle section, bottom sheet, gaskets and grommets [14].

While the channel section, angle section and bottom sheet were made of aluminium material, the gaskets and grommets were made of EPDM material. The material aluminium was selected due to its features like ductile, corrosion resistance and durability. At the same time, EPDM was selected due to its features like leak resistance and thermal durability [5].

The average thermal enhancement of the working fluid for the inlet temperatures of 30℃, 40℃, 50℃ and 60℃ was found to be 6.7, 6.3, 5.7 and 5.9℃ respectively. The average thermal performance of solar collector for the inlet temperatures of 30℃, 40℃, 50℃ and 60℃ was found to be 71.3%, 69.8%, 59.5% and 61.0% respectively. By generating a graph as per specifications, the overall thermal performance of the solar collector was estimated. It was found that the overall thermal performance was 69.9%. It was found that the estimated thermal performance was 2.2% higher than that of the solar collector with fins that had conventional coating [21]. Even though the estimated thermal performance could be correlated with utilization of opt materials and usage of suitable components in optimized dimensions, it could be specially attributed to the utilization of nano-structured coating on fins in the solar collectors [16,25].

4. Conclusion

On the basis of present research outcomes, it could be concluded that carbon and Al2O3 coated solar fins could be used in solar collector for reaping enhanced thermal performances**.**

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