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THERMAL ANALYSES ON NANO CARBON-FERRIC OXIDE COATED ABSORBER AND INTERNAL REFLECTOR INTEGRATED SOLAR HEATING DEVICE

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Abstract: Solar heating devices with increased yields of hot water are mandatory so as to match the demand and supply of hot water. The thermal investigations on these solar heating devices are also mandatory so as to efficiently operate these solar thermal devices in the application sectors. In the present investigation, the solar heating systems with toughened glass cover, nano carbon-ferric oxide coated absorber, rock wool insulator and internal reflectors of different reflecting shapes were tested. The experimental results showed that the temperature elevation of working fluid ranged between 16.9 and 28.4 0C with the corresponding thermal performance variation of 28 to 41% in the flat reflector based heating device. The experimental results also showed that the temperature elevation of working fluid varied from 27.0 to 30.4 0C with the corresponding thermal performance variation of 26 to 42% in the V-corrugated reflector coupled heating device. The experimental results also revealed that the minimum temperature elevation was 21.80C and the maximum temperature elevation of working fluid was 30.00C with the thermal efficiency variation of 33 to 43% in the U shaped reflector integrated heating device. As the nano structured absorber and U-shaped reflector integrated heating device had the highest efficiency, it could be concluded that the solar heating devices with nano structured absorber and U-shaped reflectors would be effectively used in the application sectors.

***Index Terms* – Nano composite coated absorber – Internal reflector – Solar heating device – Thermal analyses**

I. INTRODUCTION

The conventional flat plate collector is widely used for heating fluids due to its desirable structural, optical and thermal characteristics (Katumba et al., 2008). The structural characteristics of solar absorber can be further enhanced by using nano composite based coating on it. At the same time, the optical and thermal characteristics of the flat plate collector can be further enhanced by using internal reflectors. So, it is desirable to study the structural, optical and thermal characteristics of concerned components and also solar heating device with internal reflectors of different shapes (John A. Duffe and William A. Beckman, 1980). In this connection, the present investigation is devoted (i) to characterize nano carbon-ferric oxide mixed powder, which is to be embedded in the coating on solar absorber, (ii) to assess the optical characteristics of components and thermal performance of solar heating device with internal reflectors and (iii) to optimize the shapes of reflector that contributes the most in the enhancement of the thermal performance of the solar heating device. All these objectives were materialized by adopting standard methodology (BIS,2003) and the research outcomes have been presented in this research paper

II. MATERIALS AND METHODS

In the present research, the nano carbon and ferric oxide powders were procured. They were mixed in optimized proportions in black emulsion and they were stirred by using mechanical stirrer. The prepared absorption solution was spray coated on metal plate. The mixture of nano carbon and ferric oxide power was characterized and the diffractogram was generated.

The testing of the thermo - syphon domestic solar hot fluid device was carried out during sun-shine hours. In this connection, the solar hot fluid device was kept to get exposed to diverse weather conditions for two days having daily solar irradiance on the plane of solar collectors more than 18 MJ/m^2 before the test. The total duration required for each cycle of the test was seven hour, comprising 3.5 before solar noon and 3.5 hour after solar noon (BIS, 2003, MNRE, 2007). Based on not only the measured data obtained during day time test but also the formula presented as equation 1, the characteristic parameters of the solar hot fluid device were evaluated.

$$\eta_{system} = \frac{(MC)_s (T_{sfd} - T_{std})}{A_c \int_{t_1}^{t_2} G_t \, dt}$$

Efficiency (day time) ----- (1)

where,

η	Efficiency of solar hot fluid device averaged over the test period
$(MC)_s$	Thermal capacitance of the fluid in the storage tank (J/K)
T_{sfd}	Storage temperature at the end of the day-test (^{0} C)
T_{std}	Storage temperature at the start of day test (^{0} C)
G_t	Solar irradiance on the inclined plane of the Solar Collector (W/m^2)

Solar fluid heating device with variations in shapes of internal reflectors was the test sample and the thermal performances of the device were estimated in the present research (BIS, 2003, MNRE, 2007).

III. RESULTS AND DISCUSSION

In the present investigation, the dimensions of the solar heating device were measured. In addition, the solar hot fluid device with nano carbon-ferric oxide coated absorber and without the attachment of reflector was independently tested. Subsequently, the solar hot fluid device with nano carbon-ferric oxide coated absorber, flat based reflector, V-corrugated reflector and U-shaped reflector was tested (Soteris A. Kalogirou, 2013). It is worth mentioning here that the incident solar radiation was monitored by using Class 1 Pyranometer, the ambient and working fluid temperatures were recorded by using Stevenson screen and Pt_{1000} thermometer respectively. The recorded parameters during experimentation on components and solar heating device have been presented in tables for reference.

Table 1 Specifications of solar absorber

Description of solar absorber	Materials and dimensions of solar absorber
Material	Aluminium
Thickness of material	0.22 mm
Breadth of material	1050 mm
Length of material	2100 mm
Coating on solar absorber	Nano carbon and ferric coating

Table 2 Thermal performance of solar fluid heating device
(Nano-structured absorber and Flat internal reflector based device)

Day	Storage Tank Temperature (^{0}C)			Ambient temperature (^{0}C)	Solar radiation (W/m^2)	Wind speed (m/s)	Efficiency (%)
	Initial	Final	Δt				
1	30.0	53.8	23.8	28.4	598.4	0.9	38
2	35.1	60.0	24.9	27.8	587.2	0.8	41
3	40.1	62.4	22.3	27.7	600.4	0.6	34
4	45.1	66.1	21.0	27.4	603.1	0.4	31
5	50.1	72.9	22.8	27.3	576.3	0.4	34
6	55.1	74.9	19.8	28.2	603.4	0.5	28
7	60.1	77.0	16.9	27.9	572.5	0.4	26

Table 3 Thermal performance of solar fluid heating device
(Nano-structured absorber and V-Corrugated internal reflector based device)

Day	Storage Tank Temperature (^{0}C)			Ambient temperature (^{0}C)	Solar radiation (W/m^2)	Wind speed (m/s)	Efficiency (%)
	Initial	Final	Δt				
1	30.1	57.5	27.4	27.5	570.1	0.4	42
2	35.1	60.5	25.4	27.6	555.4	0.5	42
3	40.0	61.3	21.3	27.4	598.5	0.3	32
4	45.1	69.9	24.8	27.2	602.0	0.3	36
5	50.1	70.7	20.6	27.4	598.4	0.5	34
6	55.1	72.8	17.7	30.4	610.4	0.4	26
7	60.0	84.0	24.0	27.0	594.5	0.3	39

Table 4 Thermal performance of solar fluid heating device
(Nano-structured absorber and U-shaped internal reflector based device)

Day	Storage Tank Temperature (^{0}C)			Ambient temperature (^{0}C)	Solar radiation (W/m^2)	Wind speed (m/s)	Efficiency (%)
	Initial	Final	δt				
1	30.1	60.5	30.4	27.4	648.6	0.3	43
2	35.0	63.0	28.0	30.0	649.7	0.3	40
3	40.0	70.0	30.0	27.1	697.4	0.2	37
4	45.0	73.5	28.5	27.6	699.5	0.4	36
5	50.1	72.8	22.7	27.8	570.4	0.1	36
6	55.1	77.9	22.8	21.8	590.3	0.5	35
7	60.0	82.0	22.0	28.9	632.6	0.4	33

The carbon nano particles and ferric oxide nano particles exhibited intense diffraction peaks. From the XRD spectrum, the crystallite size was estimated as 70 nm using the Debye-Scherrer formula (Jeba Rajasekhar, 2018). As the crystallite size was in nano range, the optical absorption in the solar absorber would be relatively higher than that of the conventional absorber and hence the thermal performance of the solar heating device.

The experimental results showed that the thermal efficiency of fluid heating device without reflector was the lowest among the solar heating devices with and without reflectors. This was an already expected outcome, as there was no reflected radiation from the reflector that would augment the total incident solar radiation on the solar collectors. As the thermal performance enhancement in solar heating devices with reflectors was found to be considerable, the usage of internal reflectors would be desirable as per the thermal performance requirements of end users.

The experimental results also showed that the temperature elevation of working fluid ranged between 16.9 and 28.4 ^{0}C with the corresponding thermal performance variation of 28 to 41% in the flat reflector based solar collector. They also showed that the temperature elevation of working fluid varied from 27.0 to 30.4 ^{0}C with the corresponding thermal performance variation of 26 to 42% in the V-corrugated reflector coupled solar heating device. At the same time, the experimental results showed that the minimum temperature elevation was 21.8 ^{0}C and the maximum temperature elevation of working fluid was 30.0 ^{0}C with the thermal efficiency variation of 33 to 43% in the U-shaped reflector integrated solar heating device. The experimental results of the present investigation revealed that the flat reflector integrated hot water device had the relatively lower thermal performance than that of the V-corrugated reflector integrated hot fluid device. The results also revealed that the V-corrugated reflector integrated hot water system had the relatively lower thermal performance than that of the U-shaped reflector integrated hot fluid device. The enhancement of thermal performance could be correlated with the enhancement in the dimensions of reflectors, shapes of reflectors and enhancement in the reflectivity (in terms of multiple reflections) of reflectors (Tiwari et al., 1985, Vasantha Malliga and Jeba Rajasekhar, 2017, Dnyaneshwar Malwad and Vinod Tungikar, 2020, Jeba Rajasekhar, 2018). The increase in the surface area of the reflectors could have caused the augmentation of incident solar radiation on the solar collector. The nature of corrugated and parabolic shaped reflectors could have also caused the augmentation of incident solar radiation on the solar collector due to multiple reflections by the ridged reflecting materials. As the incident solar radiation was increased due to the use of reflectors, the absorption of the solar radiation would have been increased due to the usage of nano structured absorber. As the absorption of solar radiation was augmented, the heat transfer to the working fluid would have also been augmented. The above-mentioned process would have increased the thermal performance of the heating device and so the corrugated and parabolic shaped reflector integrated solar heating device had the highest thermal efficiency (Kennedy and Kent Terwilliger, 2005, Anuradha and Rachel Oommen, 2013, El-Sebaii et al., 2011, Saravanan et al., 2016). So, it could be recommended to utilize nano-structured absorber along with U-shaped reflectors in the solar hot fluid device so as to have its effective utilization.

IV. CONCLUSION

It could be concluded that the solar heating device with nano-structured absorber and parabolic shaped reflectors would be used not only to have enhancement in the temperature of the working fluid but also to have enhancement in the thermal performance of the solar heating devices

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