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THEORETICAL PREDICTION OF THERMAL PERFORMANCE OF SOLAR COLLECTOR WITH NANO SIZED CARBON AND TITANIUM OXIDE COATED ABSORBER

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ABSTRACT

Nano-structured components are necessitated not only to have improved structural, optical and thermal characteristics but also to have enhanced thermal performance of solar thermal collector integrated with these nano-structured components. In this connection, the present research was carried out to study the characteristics of the nano-structured components and to predict the thermal performance and loss of solar collector integrated with these nano-structured components. It was found that the transmittance of nano-textured glass cover, absorptance of the nano-structured absorber and thermal conductance of the novel insulation were 91.0%, 85.0% and1.02 W/m^2 ˚C respectively. It was also found that the sizes of the crystallites in the solar absorptive coating effected on the absorber were in nano ranges. Subsequently, the thermal performance and losses of solar collector integrated with the C-TiO_2 coated absorber were theoretically predicted. The theoretical researches revealed that the predicted thermal performance and loss coefficients of solar collector with C-TiO_2 coated absorber were 71.0% and 5.37 W/m^2 respectively. On the basis of research outcomes of the present investigation, it could be concluded that solar air heating collectors would be designed, developed and deployed with nano-textured glass cover, nano-structured absorber and novel wool so as to reap enhanced thermal performance and reduced thermal losses.

Keywords: Nano-structured components – Solar collector – Theoretical prediction of performance

INTRODUCTION

Nano structured solar absorber can either be procured or prepared for their utilization in solar collector. The utilization of this absorber shall yield not only the improved optical and thermal characteristics but also the improved thermal performances of solar collector (Katumba et al., 2008). In this connection, the present research work was devoted for assessing the structural, optical and thermal characteristics of absorber with the coating that contained nano sized carbon and titanium oxide. Prediction of thermal performance of solar collector integrated with the nano structured absorber was also done. The research outcomes pertaining to experimentally assessed structural, optical and thermal characteristics of the integral components of solar collector have been documented in this research paper. Theoretically predicted thermal performance of solar collector integrated with the nano-structured integral components has also been reported. These results would be beneficial to the manufacturers, researchers and end users of solar thermal devices worldwide.

Materials and methods

Test samples

The test samples of the present research work included nano textured glass cover (2120 mm x 2120 mm), nano structured copper absorber (2120 mm x 2120 mm) and novel insulation material (25 mm and 50 mm thickness).

The test samples used for the measurement of dimensions in the present research work included foil for coverage, angle section, channel section, bottom sheet and gaskets.

Methods for assessment of characteristics

The BIS specifications were adhered to the assessment of optical characteristics of nano textured glass cover. The XRD techniques were adopted for the assessment of

Structural characteristics of the prepared nano textured absorber. The standard specifications were adhered to the assessment of thermal characteristics of nano textured absorber and novel insulation (BIS, 2003, MNRE, 2007).

Method for theoretical predictions

In the present research work, top and bottom loss coefficients and heat transfer coefficients were calculated by using the standard equations. The overall loss coefficient of the solar collector was predicted by

$$U_L = \frac{(Ub+Ut)(h1h2+h1hr+h2hr)+UbUt(h1+h2)}{h1hr+h2Ut+h2hr+h1h2} \quad \ldots (1)$$

Where U_L is overall loss coefficient, U_b is bottom loss coefficient and U_t is top loss coefficient. The h_1 is the heat transfer coefficient (that is calculated due to heat transfer from working fluid to the glass cover), h_2 is the convection heat transfer coefficient (that is calculated due to heat transfer from the glass cover to the ambient atmosphere) and h_r is the radiative heat transfer coefficient.

In the present research work, the thermal performance of solar collector was predicted by

$$\eta = Q_u / IA_c \quad \ldots (2)$$

where Q_u is the collector useful energy gain (W), I is the solar radiation (W/m^2) on the heater surface and A_c is the surface area of the collector (m^2) (John A. Duffie and William A. Beckman,1980).

Results and discussion

The materials and sizes of the major and supporting components used in solar collector have been presented from Table 1 to Table 3. The incident radiation on the glass cover and transmitted solar radiation through the glass cover were experimentally estimated and the transmittance of the glass cover was found. At the same time, the absorptance of the absorber was found by using alphotometer, the thermal resistivity of insulation was found by using the thermal resistance meter. The estimated transmittance of nano textured glass cover, absorptance of nano structured absorber and thermal conductance of novel insulation are given in Table 4. The diffractogram of the nano-sized carbon and titanium oxide coating has been presented in figure 1. The heat loss coefficient and the thermal performance of the solar collector were predicted and the theoretical predictions have been presented in Table 5.

Table 1 Materials of major and supporting components in air heating collector

Components	Materials
Glass cover	Nano-textured glass
Absorber	Copper with C-TiO_2 coating
Insulation	Novel wool
Channel section	Aluminium
Angle section	Aluminium
Gaskets	Neoprene
Grommets	Neoprene
Enveloping cover	Aluminium
Bottom sheet	Aluminium

Table 2 Sizes of major components in air heating collector

Components	Sizes (mm)		
	Length	Breadth	Thickness
Glass cover	2200	1100	4
Absorber	2200	1100	2
Insulation (bottom)	2200	1100	60

Table 3 Sizes of supporting components in air heating collector

Components	Sizes (mm)		
	Length	Breadth	Thickness
Channel section	2222	1102	1.6
Angle section	2222	1102	1.2
Enveloping cover	2220	1102	1.0
Bottom sheet	2220	1100	0.7
Gasket	2220	1100	0.8

Figure 1 Diffractogram of solar absorptive coating with nano sized carbon and titanium oxide

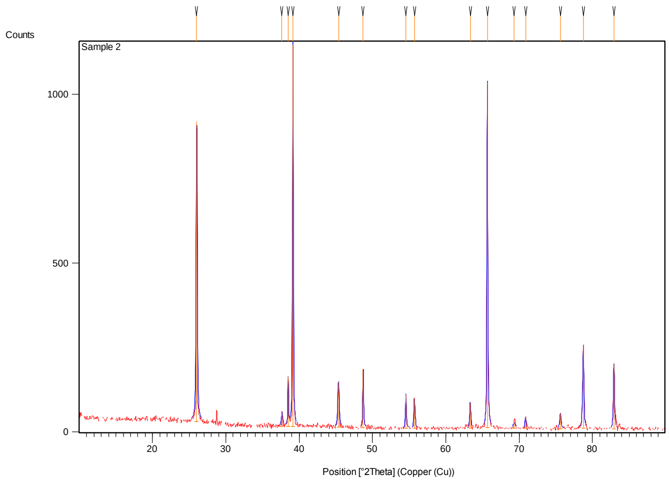

Table 4 Estimated optical and thermal parameters of solar components

Solar components	Optical / thermal characteristics
Glass cover	Transmittance of 91.0%
Absorber	Absorptance of 85.0%
Insulation	Thermal conductivity of 1.02 W/m^2 °C

Table 5 Theoretical prediction thermal parameters of air heating collector

Heat loss coefficients	Predicted value
Edge loss coefficient	0.48 W/m^2
Bottom loss coefficient	0.91 W/m^2
Top loss coefficient	3.97 W/m^2
Overall loss coefficient	5.37 W/m^2
Thermal performance	71.0%

The major components such as nano textured glass cover, nano structured absorber and novel wool that were chosen for the design and fabrication of solar collector was of recent origin. While the transmittance of nano-textured glass cover was experimentally estimated to be 91.0%, the absorptance of the nano-structured absorber was experimentally quantified to be 85%. The XRD diffractotgram of the coating on the solar absorber revealed that the sizes of the crystallites in the coating were in nano ranges. The thermal conductance of the novel insulation was experimentally assessed to be 1.02 W/m^2 °C. All these factors would have caused for the improved structural, optical and thermal characteristics of the components than those of the conventional components (Uma Maheswari and Jeba Rajasekhar, 2015). The materials of the secondary components such as angle section, gaskets, grommets, enveloping cover and bottom sheet that had been chosen for the design and fabrication of solar collector were fixed as per BIS specifications. So, the non leakage of working fluid, safety of integral components and durability of solar collector were ensured (BIS, 2003, MNRE, 2007).

The sizes (lengths, breadths and thicknesses) of the major components chosen for the design and fabrication of solar collector were fixed to be optimum as per specifications. The sizes (lengths, breadths and thicknesses) of the secondary components chosen for the design and fabrication of solar collector were also fixed to be optimum as per specifications (BIS, 2003, MNRE, 2007). As the component materials were of recent origin and component sizes were optimal, the predicted thermal performance of solar collector was found to be higher than those of the other conventional collectors. At the same time, the predicted thermal loss of the solar collector was found to be lower than those of other conventional collectors.

In the present research work, a set of heat balance equations were solved so as to predict the thermal performance and losses of the solar collector. It was found that the theoretically predicted thermal performance of solar collector was 71.0%. The level of thermal performance of solar collector could be attributed with the design parameters such as optimized sizes of components, optimized sizes of collectors and presence of air flow path in optimized dimensions and also the fabrication parameters such as usage of opt materials as components, opt materials as collectors and fixation of novel flow paths on solar absorbers. It was also found that the loss in thermal performance of solar collector was 29%. The loss in thermal performance of solar collector could be attributed with optical losses such as radiative losses from the glass cover, convective losses from the glass cover, radiative losses from the absorber and convective losses from the absorber and also thermal loss coefficients such as bottom loss coefficients and top loss coefficients of solar collectors (John A. Duffie and William A. Beckman, 1980).

Conclusion

As the theoretically predicted thermal performance and losses were found to be satisfactory, it could be concluded that solar air heating collectors would be designed, developed and deployed with nano-textured glass cover, nano-structured absorber and novel wool on any scale, as per requirement of end user.

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