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Experimental estimation of the thermal performances of copper, aluminium and mild steel absorber integrated solar collectors

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Abstract
The requirement of heat energy for diverse applications can be fulfilled by the effectual conversion of the incident solar radiation through solar thermal gadgets. The central component of any solar thermal gadget is the solar collector, which is used with different absorber materials nowadays for heating fluids. At this juncture, it is essential not only to study the thermal characteristics of the absorber materials but also to estimate the thermal performances of the collectors with different absorber materials for effective utilization in application sectors. In this connection, in the present investigation, three commercially available solar collectors with copper, aluminium and mild steel absorbers were tested as per IS 12933 (Part 1, 2 and 5): 2003. As an integral part of this investigation, the temperature test on black chrome coated copper, aluminium and mild steel fins at the temperature of 175 °C for 2 hours was conducted and it was found that there were no appearances of blistering, rupture and peeling off the coated surface on the absorber plates. The thermal performance test on the solar flat plate collectors of current concern was also conducted and it was found that the instantaneous thermal performances varied from 66.8 to 69.2%, ranged between 62.1 and 65.9% and had a minimum of 58.1 and a maximum of 60.1% for copper, aluminium and mild steel absorber integrated solar collectors respectively for the inlet temperature of 30 °C of the working fluid. It was also found that the instantaneous thermal performances varied from 65.1 to 66.6%, ranged between 61.2 and 62.5% and had a minimum of 54.8 and a maximum of 55.9% for copper, aluminium and mild steel absorber integrated solar collectors respectively for the inlet temperature of 40 °C of the same working fluid. As the thermal performances of the solar collectors could depend on the thermal conductivity of the absorber materials, it could be concluded that either copper or aluminium or mild steel absorber would be used in application sectors as per temperature requirements of the end users.

Keywords: Solar collectors, absorbers, alternate materials, thermal performances

1. Introduction
India is in tropical region and hence maximum irradiance, i.e., 7600 to 8000 M J m^{-2} per annum is received in most parts of this country. While semi arid areas receive 7200 to 7600 M J m^{-2} per annum, the mountainous regions receive 6000 M J m^{-2} per annum country. This incident solar irradiance can effectively be utilized by deploying solar thermal systems in various energy intensive sectors. Solar water heaters that consist of flat plate collectors coupled with storage tanks are one of the major solar thermal systems that have been commercialized during the last three decades in the country and it is worth mentioning that a substantial number of solar flat plate collectors are manufactured in the southern states of India. Flat plate collectors with alternative material components are preferred nowadays mainly due to their cost effectiveness and so it is essential to quantify exactly the variations in the thermal performances of the collectors with these alternative material components.

2. Materials and Methods
The test samples of the present investigation included copper, aluminium and mild steel absorber integrated solar collectors. The test methods presented in IS (Indian Standards) specifications of solar flat plate collectors IS 12933 (part 1, 2, 3 & 5: 2003 together with amendment No.1 of June 2005) were followed to test these collectors. As part of the specifications, the thickness of glass cover, absorber sheet, support for the glass, coverage foil, bottom sheet and channel section were measured. The diameters of risers and headers were also taken.

The thermal performance of a non-concentration solar collector operating under steady state conditions can be described as

$$Q/A_g = G\, F_R\, (\tau\alpha)_e - F_R\, U_L\, (T_i - T_a) \quad (1)$$

The useful energy extracted by the solar collector may be expressed as

$$Q/A_g = m\, C_f / A_g\, (T_o - T_i) \quad (2)$$

If the thermal performance of a solar collector is defined as a ratio of the actual useful energy collected to that of the solar energy intercepted by the gross area of solar collector, then the performance of non – concentrating collector may be defined as

$$\eta = F_R\, (\tau\alpha)_e - F_R\, [Ti - Ta / G] \quad (3)$$

The equation (3) indicates that the thermal performance of a flat plate solar collector is a linear function of (Ti - Ta)/G assuming that U_L is constant. So, graphical representation of data can be made in terms of (Ti – Ta/G) Vs η and the overall performance can be found by noting the value of y intercept. The equation (3) can be written in terms of an instantaneous performance as

$$\eta_i = Q / A_g\, G = F_R\, (\tau\alpha) - F_R\, (T_i - T_a)/ G \quad (4)$$
$$\eta = m\, C_p\, (T_0 - T_i)/A_g\, G \quad (5)$$

Where m is mass flow rate, C_p is specific heat of heat transfer fluid (J/kg °C), F_R is heat removal factor of solar collector (Dimensionless), T_i is inlet temperature (°C), $T_o$is outlet temperature (°C), T_a is ambient temperature (°C), A_g is collector gross area (m^2), G is solar irradiance on collector plane (W/m^2), Q is rate of useful energy extraction from the solar collector (W), $(\tau\alpha)_e$ is the product of absorptance and transmittance (Dimensionless), η is collector performance (%) and U_L is overall heat loss coefficient of solar collector (W/m^2 °C).

In the test of thermal performance, the steady state conditions, which have been presented in Table 1, were maintained. In addition, the test conditions such as (a) Total solar irradiance at the plane of collector aperture more than 700 W/m^2 (b) Average value of the surrounding air speeds in between 2 and 5 m/s and (c) Fluid flow rate at the rate of 0.02 Kg/s m^2 based on collector gross area were also maintained.

Table 1: Steady state conditions

Sl. No	Parameter	Deviation from the mean value over the test period
1	Total solar irradiance	±50 W/m^2
2	Surrounding air temperature	± 1 °C
3	Fluid mass flow rate	± 1 percent
4	Collector fluid inlet temperature	± 0.1 °C
5	Temperature difference between collector inlet and outlet	± 0.1 °C

The measurements such as solar irradiance at the plane of the collector aperture, inlet temperature of working fluid, outlet temperature of working fluid, ambient air temperature and mass flow rate were carried out for two inlet temperatures such as 30 and 40 °C of the working fluid. Subsequently, the instantaneous performances were calculated using the equation (5).

3. Results and Discussion

In the present investigation, the three test samples, which were the solar collectors integrated with copper, aluminium and mild steel absorbers, were tested by adopting the test methods presented in IS (Indian Standards) specifications of solar flat plate collectors IS 12933 (part 1, 2, 3 & 5: 2003 together with amendment No.1 of June 2005. As part of the specifications, all the measurements on components were carried out and they have been presented in Table 2.

Table 2: Technical specifications of solar components and collectors

Components / Parameters	Materials / Measurements
Glass cover	
Material	Toughened
Transmittance	82.6%
Absorber	
Material	Copper, aluminium and mild steel
Coating	Selective coating
Bonding between riser and absorber	Laser welding
Insulation material	
Material	Rockwool
Side insulation thickness	25 mm
Back insulation thickness	50 mm
Side insulation thermal conductivity	1.72 m^2 °C/W
Back insulation thermal conductivity	0.86 m^2 °C/W
Cover of side and back insulation	Aluminium foil
Collector box	
Material	Aluminium
Thickness of channel section	1.70 mm
Thickness of sheet for bottom	0.47 mm
Thickness of support for glass retention	1.60 mm
Gaskets and Grommets	
Material	EPDM
Collector	
Size	2080 x 1068 x 98
Workmanship and finish	Satisfactory*

* Surface was smooth, free from roughness, free from raised spots, free from scales and free from sharp edges. There were no sharp edges and the corners were in the rounded off position. All the screw joints were fixed so as to be leak proof.

It was noted that there were specifications for the thicknesses of all these components except glass covers and foils in IS specifications and all the rest of the components that were measured had the dimensions as per specifications. The integral components such as foil, sheet for bottom, angle section and channel section have been made by aluminum sheets but with different thicknesses. In line with the specifications, aluminium foils have been used for covering the back as well as side insulation. In addition, aluminium sheets have been used as sheets for bottom and angle section with the specified thicknesses.

The temperature test for coating was conducted on the absorber sheets and it was observed that there were no appearances of blistering, rupture and peeling off in the coated surfaces. It was also observed that these were no weakening of the bonding between absorber sheet and risers as well as headers. In addition, the instantaneous efficiencies of solar collectors with alternate materials for the initial water temperature of 30 °C and 40 °C were experimentally found and they have been presented in Table 3 and Table 4 respectively.

Table 3: Instantaneous efficiencies of solar collectors with alternate materials (For the initial water temperature of 30 °C)

Time	Instantaneous efficiency (%)		
	For copper absorber	For Aluminium absorber	For mild steel absorber
11.00	69.2	65.9	60.1
11.30	67.6	63.0	59.4
12.30	66.8	62.1	58.1
13.00	67.0	64.8	58.2

Table 4: Instantaneous efficiencies of solar collectors with alternate materials (For the initial water temperature of 40 °C)

Time	Instantaneous efficiency (%)		
	For copper absorber	For Aluminium absorber	For mild steel absorber
11.00	65.1	62.0	55.9
11.30	65.9	61.2	55.4
12.30	66.6	62.1	54.8
13.00	66.0	62.5	55.2

The outlet temperatures of the working fluid were measured and the elevations in temperatures were found from its different inlet temperatures. It was found that the instantaneous thermal performances varied from 66.8 to 69.2%, ranged between 62.1 and 65.9% and had a minimum of 58.1 and a maximum of 60.1% for copper, aluminium and mild steel absorber integrated solar collectors respectively for the inlet temperature of 30 °C of the working fluid. It was also found that the instantaneous thermal performances varied from 65.1 to 66.6%, ranged between 61.2 and 62.5% and had a minimum of 54.8 and a maximum of 55.9% for copper, aluminium and mild steel absorber integrated solar collectors respectively for the inlet temperature of 40 °C of the working fluid.

As it was known, the major integral component namely absorber sheet was made up of copper, aluminium and mild steel materials in the collectors of current concern. It was noted that the existing thicknesses of the absorber sheets might have been chosen so as to ensure adequate strength and stability against the pressures to prevent swelling, distortion or ruptures. Of course, the collectors had absorber sheets with selective coating, though non – selective coating has been permitted in IS specifications. As block chrome was used as selective coating in all the absorbers, the absorptance was 96% in all the absorber sheets. But, there were variations in the increase in temperatures of the working fluid that might be due to the thermal conductivity of absorber materials to the working fluid. It was obvious from the generated results of thermal performances that higher the temperature differences between the conductor and the working fluid, higher would be the heat transfer rates of conductor to the working fluid. Evidently, the estimated enhanced thermal performances of all these three collectors might be correlated with enhanced transmittance of the cover plates due to the usage of toughened glass covers, increased absorptance of the absorber sheets due to the utilisation of copper, aluminium and mild steel absorber plates with selective coating, improved heat transfer between absorber sheets and risers due to the laser welding, and reduced heat losses due the presence of rock wool with suitable thicknesses and reduced heat losses to the surroundings due to the presence of opt gaskets.

4. Conclusion

As the thermal performances of the solar collectors could depend on the thermal conductivity of the absorber materials, it could be concluded that either copper or aluminium or mild steel absorber would be used in application sectors as per temperature requirements of the end users.

5. References

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