

Effect of Selective Coatings on Solar Absorber for Parabolic Dish Collector

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Abstract

Objectives: The effect of selective coatings on the solar absorber of a Parabolic Dish Collector (PDC) is presented in this work. **Methods/Statistical Analysis:** Outdoor experiments performed on sunny days at a 16 square meter. PDC with selective absorber of 0.4 m diameter. The Mild Steel (MS) absorber plates coated with nickel and chromium for their low emissivity and high absorptivity using the electroplating process with thicknesses of 30 μm . **Findings:** Instantaneous efficiency, radiative and convective heat losses evaluated for the absorber. The efficiency of collector system is highest when the mild steel absorber plate coated with nickel. **Application/Improvements:** The solar selective coatings are more beneficial in the energy transfer and economical to the consumers. The consistent higher absorption rate at the outdoor climate has to attain with a long life coating.

Keywords: Parabolic Dish Collector, Selective Coating, Solar Absorber, Solar Concentrator

1. Introduction

A solar parabolic dish concentrator is a collector system in which designed to collect thermal energy by concentrating direct sunlight. The solar concentrating system in which the absorber is plays an important role to collect the heat energy. In the working of the solar collectors, the solar absorber gets heated up due to the solar radiation incident and transfers the heat to the Heat Transfer Fluid (HTF). The different types of solar thermal collectors with the optical and thermodynamic performance of the collectors reviewed by¹. The modeling and experimental study on solar collectors are carried out by²⁻⁴. Energy conservation measures on solar, and wind energy is discussed by⁵⁻⁷. The effect of temperature distribution on surface absorption receiver in a parabolic dish solar concentrator with and without PCM was studied by⁸⁻¹⁰. The improvement in efficiency of solar cells is demonstrated by¹¹. The study of black coating for solar applications reported by several authors. The objective of present work is to explore and investigate the performance of parabolic solar collector with coated absorber. The different absorber coatings

investigated for PDC, and the results reported, testing regular sunny days.

2. Methods and Materials

An experimental set-up is used to analyze the thermal performance of solar PDC with coated absorbers. The experimental set-up consists of 16-square meter² PDC, absorber, storage tank, pump, and flow meter and flows control valve. The schematic diagram of the experimental set-up is shown in Figure 1. The incident solar radiation on PDC and concentrated on the absorber. The water storage tank is 110 liters which are filled entirely with soft water, and the connected pump used for circulation. The flow controlled by a control valve and measured with a rotameter. The receiver is 400 mm in diameter and 100 mm deep. The metal used is 5 mm thick. MS receiver is a hollow circular vessel with 1-inch pipes coming out of its top and bottom. It has a provision for changing its covering receiver plate, by removing the eight bolts that hold the plate to the hollow receiver.

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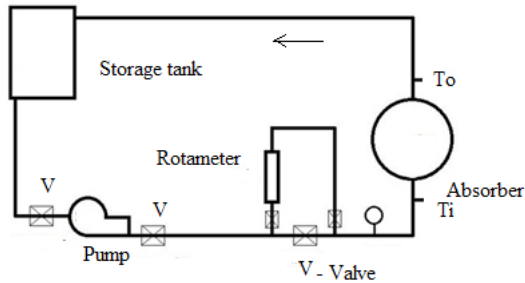


Figure 1. Schematic of experimental setup.

The inlet and outlet pipes coming out of the receiver welded on the receiver. The absorber has an inlet and an outlet port. K-type thermocouples inserted into the entry and exit of the receiver. The entire system insulated with glass wool of 30 mm thickness. All three plates are made from MS plate with a thickness of each plate 5 mm.

The choice of MS is made due to the relative ease of availability of the metal, its cost effectiveness, and most importantly, its physical properties that are essential for its performance as a good absorber plate. MS has a melting point of 1450°C, density of 7.85 g/cm³ and emissivity of 0.16. A low emissivity value leads to low emissive heat loss. The plates of the receiver are changed to compare the efficiency of the receiver. The plates with and without coating are tested in the experiment. Ni has high absorptivity and low emissivity values. These parameters are pertinent to high absorptivity. A low emissivity value means that a low amount of the incident radiation would be emitted by the plate and would mostly retain. The properties of MS plate electroplated with Ni are emissivity of 0.08 and the absorptivity of 0.92. The properties of Cr, though not as good as Ni, are still good enough to be tried as an alternative to the MS Plate. The properties of MS plate electroplated with Cr emissivity of 0.11 and absorptivity of 0.88. The plates are placed on the receiver and fixed with bolts. The experiments conducted as per ASHRAE standards¹².

3. Performance Analysis

Heat losses occur from a receiver due to the temperature difference between the receiver and its surroundings. Total heat losses from the receiver are conductive losses, convective losses, and radiation losses. The geometry of the set-up is as given in Table 1.

Table 1. Geometry of experimental setup

Geometry	values
Area of Receiver (A_1)	0.1257 m ²
Area of the Reflector (A_2)	16 m ²
Radius of Receiver (r_1)	0.2 m
Radius of the Reflector (r_2)	2.257 m
Distance between Receiver and Reflector (L)	3.4 m
Area of Air Wall (Frustum of Cone) (A_3) is equal to $\pi(r_1 + r_2)[(r_2 - r_1)^2 + L^2]^{0.5}$	30.67 m

The following relation can use as to find shape factor consider the reflector and receiver as two co-axial discs,

$$F = 0.5 \left\{ s - \left[s^2 - 4 \left(\frac{r_2}{r_1} \right)^2 \right] \right\} \quad (1)$$

$$\text{where, } s = 1 + \left(\frac{1 + R_2^2}{R_1^2} \right) \text{ and } R_1 = \frac{r_1}{L}, R_2 = \frac{r_2}{L}.$$

The shape factor between the surfaces obtained by Substituting the values for r_1, r_2 and L in the equation and also using the summation rule and by the Reciprocity relation. For enclosures with specified surface temperatures, the following relation can be used to obtain the radiosities (J) of the surfaces.

$$\sum_{j=1}^N F_{ij} (J_i - J_j) \quad (2)$$

$$\sigma T_i^4 = J_i + \left\{ \frac{(1 - \varepsilon_i)}{\varepsilon_i} \right\} \quad (3)$$

Applying the above equation, For the receiver, reflector and side walls determined by using the expression:

$$\sigma T_i^4 = J_i + \left\{ \frac{(1 - \varepsilon_i)}{\varepsilon_i} \right\} [F_{ij} (J_i - J_j) + F_{ik} (J_i - J_k)] \quad (4)$$

Hence, the heat transferred from the receiver can be calculated as, $Q = J.A$ Watts. Equation (5) is used to estimate the rate of heat loss from the receiver,

$$Q_{cond} = \frac{T_r - T_a}{\left[\left(\frac{1}{A_{ms} h_w} \right) + \frac{1}{k_{ins}} (A_w - A_0)^{0.5} \right]} \quad (5)$$

Convective heat loss of the receiver to the surroundings can express as,

$$Q_{conv} = h_{conv} A (T_r - T_{amp}) \quad (6)$$

where, U_L is the heat loss coefficient determined in $W/m^2 K$, A_r is the effective receiver area in square meter, T_{av} is the average of T_{in} and T_{out} , and T_{amp} is the ambient temperature in K.

$$Nu = 0.332 \left(\frac{V_w D_r}{\nu_w} \right)^{0.5} Pr^{0.33} \quad \text{for } 0.6 < Pr < 5 \quad (7)$$

The following equation uses the general equation for total radiation heat transfer due to emission,

$$Q_{rad} = A \varepsilon \sigma (T_r^4 - T_{amp}^4) \quad (8)$$

Thermal efficiency obtained by measuring the temperature difference of working fluid through the receiver, together with fluid properties, mass flow rate, and solar direct radiation incident. Thermal energy efficiency of the collector based on heat gained by working fluid expressed as:

$$\eta_{th} = \frac{\dot{m} C_p (T_{out} - T_{in})}{I_b A_p} \quad (9)$$

where, $\dot{m}$ is the rate of flow of HTF, C_p is the specific heat of HTF, A_p is the absorber plate area I_b is the incident beam radiation, $T_{out} - T_{in}$ is the temperature difference of water inlet and outlet in the absorber.

4. Results and discussion

The experimental test is carried out to investigate the performance behavior of the PDC with different coating absorber. The performance of the dish solar concentrator can characterize by an estimation of the stagnation temperature and performance test at constant solar energy input with the same period interval. The direct solar radiation, wind speed, and ambient temperature are observed using pyranometer, anemometer, and K-type thermocouples respectively. The experiments conducted during April 2016 in Chennai climate. The average solar radiation around 760 – 820 W/m^2 only considered in the heat loss and performance calculations. The stagnation test is often the preliminary test to compare the characteristics of the different plates. The temperature of a collector

system measured in periods of time under no fluid flow conditions as referred the stagnation temperature. It considered for designing of the solar collector, absorber, selection of absorber material, working fluid, hot water tanks and other auxiliary equipment. The useful heat gains by the absorber plate yields evaluated with the following equation:

$$Q_u = A_p S - Q_l \quad (10)$$

At stagnation condition, $Q_u = 0$, Where S is the incident solar flux and Q_l is the total heat loss. The tests

are performed for MS and with Ni and Cr coating, and the average value of stagnation temperature is 516, 531 and 523°C for incoming radiation of 780.62, 772.098, 817.36 W/m^2 . The radiation heat losses are found to be greatest in the MS Plate (94.24 W). Ni and Cr exhibited similar radiation heat loss. It indicates that the electroplated absorbers lose less heat due to radiation. On examining the convective heat, losses are found to be lowest in the Cr plated absorber (148.6 W) and considerably higher in the other two plates. It shows that the heat loss due to convection most aptly controlled by the electroplating of Cr on MS. The heat losses of the selective absorber plate as shown in Figure 2.

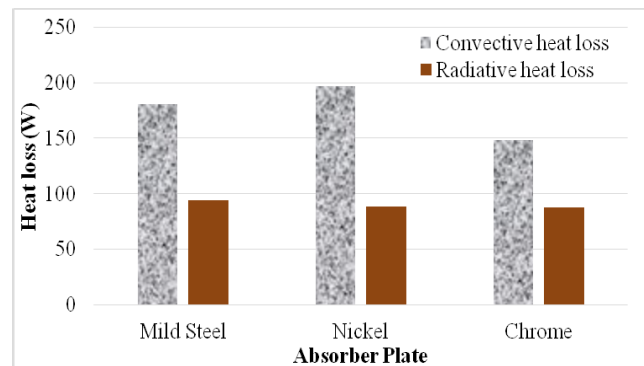


Figure 2. Heat losses of selective absorber plates.

The HTF temperature at inlet and outlet temperature of the absorber plate and atmosphere temperature readings are taken and recorded in every five-minute time interval. The experiment tests restricted to collector within operating temperature of 100°C. A temperature difference of inlet and outlet heat transfers fluid (HTF) variation for different coated absorber plates obtained and as shown in Figure 3.

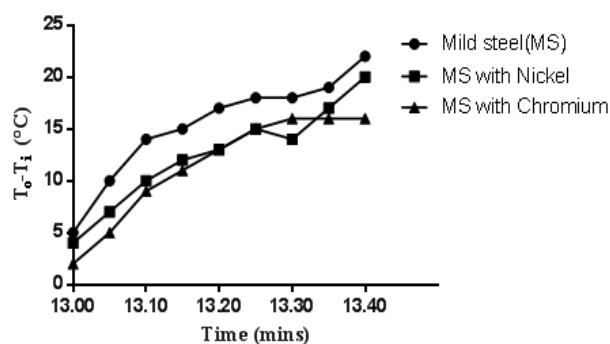


Figure 3. Variation of $T_o - T_i$ for different coating absorber plates.

Figure 4 indicates that the absorber temperature obtained by the Ni plate is higher than that of the other two plates, thereby providing the higher amount of energy for the heat exchanger to absorb. So the among three plates, by using MS with Ni coated plate provides higher performance of collector.

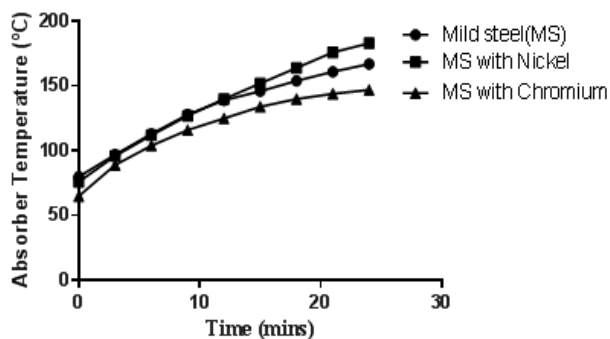


Figure 4. Variation of absorber temperature for various coating absorber plates.

Figure 5 shows that the efficiency of our collector system is highest when the MS absorber plate is electroplated with Ni. It would mean that the heat available for useful work would be highest with the Ni-plated absorber, thereby justifying our hypothesis and preliminary tests which suggested that MS Electroplated with Ni is the best choice for our PDC.

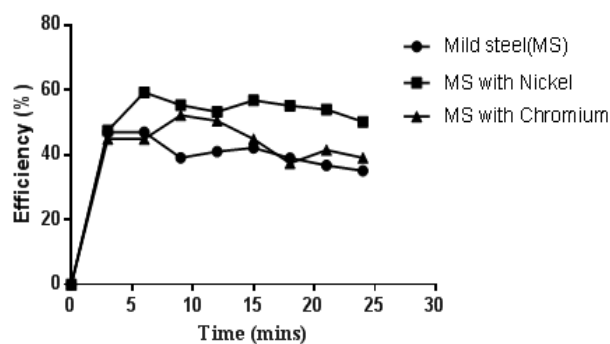


Figure 5. Variation in efficiency for different coating absorber plates.

5. Conclusion

Experimental investigations of the solar PDC with and without coating on absorber plates were carried out to determine the efficiency of the receiver. MS plate with Ni coating has the highest stagnation temperature about 531°C among the three plates. The heat available for useful work would be highest with the Ni-plated absorber. The radiation heat loss is more for the MS absorber without coating about 94.24 W. Ni, and Cr exhibited low heat losses under similar radiation conditions. The convective heat loss found as lowest in the Cr plated absorber about 148.6 W. This indicates that the heat loss due to convection mostly controlled by the electroplating of Cr on MS. The Ni coating on MS absorber produces effective heat absorption.

6. References

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