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ENERGY AND EXERGY ANALYSIS OF A PARABOLIC DISH CONCENTRATED SOLAR RECEIVER WITH INTEGRATED PCM

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ABSTRACT

The parabolic dish solar receiver was tested with and without phase change material (PCM) to ensure uniform heat flux inside the receiver. The PCM was D-Mannitol with a melting temperature of 117 ℃. The exergy efficiency was increased twice that of without PCM case.The operational duration was reduced by 9% to attain the boiling point of water in case of receiver with PCM and the energy efficiency was increased by 4.5%. The improved energy utilization in the receiver was observed with PCM in the receiver.

Keywords: Parabolic Dish, Solar Receiver, Phase Change Materials, Exergy Analysis, Energy Analysis

I. INTRODUCTION

The main purpose of this study is to perform the energy and exergy analysis for a solar concentrated receiver with PCM. Kumaresan et al. [1] investigated the thermal properties of D-Mannitol as a phase change material for latent heat storage system. The parabolic dish collector with integrated storage in the receiver is numerically studied by Tao et al. [2]. The solar receiver is located at the focal point of the solar dish concentrator. The energy and exergy performance of solar dish concentrator was carried out to find the thermal performance [3, 4]. Solar parabolic dish receiver was extensively analyzed for its temperature distribution, operational characteristics and use of PCM in the receiver by Senthil and Cheralathan [5-7]. A detailed review of the literature review shows that there is a very little information on solar collectors with PCM. It was also found that Sugar alcohols as phase change materials (PCM) are very promising due to their high storage capacity, safety and economic reasons.

II. EXPERIMENTAL WORK

A 16 m^2 parabolic dish solar concentrator is made up of an elliptical hardened steel frame with 800 number of mirrors are fitted on the frame. The tracking of the parabolic dish is done manually. The receiver is made up of mild steel and the thickness of the material is 5mm, insulation of the receiver is done with glass wool of 30 mm thickness. The diameter of the absorber is 406mm and width of the absorber is 150 mm. The piping includes 0.025 m diameter pipe with 9 m long insulated with 30 mm thick glass wool. The selected phase change

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material (PCM) is D-Mannitol. It has melting temperature of 117 °C and melting enthalpy of 330 kJ/kg. The receiver is tested with and without PCM in real outdoor conditions.

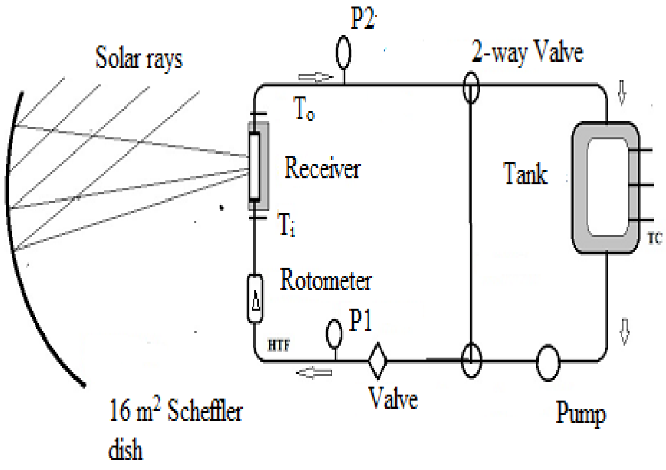

Fig 1. Schematic Layout of Experimental Setup

III. ENERGY AND EXERGY ANALYSIS

The energy and exergy analysis were carried out based on the operating parameters like mass flow rate, heat gain and heat losses from the receiver. Useful heat gain by the HTF is given by Duffie Beckmann [8],

$$Q_u = \dot{m}C_p(T_o - T_i) \tag{1}$$

The overall heat loss coefficient can be calculated by

$$U_l = \frac{Q_l}{A_r(T_r - T_a)} \tag{2}$$

Thermal efficiency, $\eta = \dfrac{Qu}{(A_c I_b)}$ (3)

The exergy input includes both the exergy inflow rate coming from the heat transfer fluid and the exergy of the solar radiation.

The total exergy input is given as

$$\dot{E}_i = \dot{m}\left[\int_{T_0}^{T_i} C_p(T)\,dT + v(p_i - p_0) - T_0\int_{T_0}^{T_i}\frac{C_p(T)}{T}\,dT + \frac{V_i^2}{2}\right] + I_b A_a \varphi \tag{4}$$

Where,

$\dot{m}\int_{T_0}^{T_i} C_p(T)\,dT$ represents the exergy gain as a result of an increase in the heat transfer fluid temperature due to fluid temperature due to the solar insolation.

$\dot{m}\,v(p_i - p_0)$ represents the exergy due to the annulus gas pressure.

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$\dot{m}T_0 \int_{T_0}^{T_i} \frac{C_p(T)}{T} dT$ represents the exergy due to flow friction.

The maximum amount of useful work available from radiation φ is given by

$$\varphi = 1 - \frac{4}{3}\frac{T_0}{T_s}(1 - cos\delta)^{\frac{1}{4}} + \frac{1}{3}\left(\frac{T_0}{T_s}\right)^4 \quad (5)$$

The exergy output consists of the exergy outflow rate coming from the heat transfer fluid exiting the solar receiver.

$$\dot{E}_e = \dot{m}\left[\int_{T_0}^{T_e} C_p(T)dT + v(P_e - P_0 - T_0 \int_{T_0}^{T_e} \frac{C_p(T)}{T} dT + \frac{V_e^2}{2}\right] \quad (6)$$

The exergy gained by the heat transfer due to the incident radiation on the solar collector is given by

$$\dot{E}_{gain} = \dot{m}\left[\int_{T_i}^{T_e} C_p(T)dT - T_0 \int_{T_i}^{T_e} \frac{C_p(T)}{T} dT - v\Delta P\right] \quad (7)$$

The term $v\Delta P$ represents the decrease of the mechanical energy due to flow friction.

Exergy efficiency is given as the ratio of the exergy gain to solar radiation exergy

$$\eta_{ex} = \frac{\dot{E}_{gain}}{\dot{E}_{sr}} = \frac{\dot{m}\left[\int_{T_i}^{T_e} C_p dT - T_0 \int_{T_i}^{T_e} \frac{C_p}{T} dT - v\Delta P\right]}{I_b A_a \varphi} \quad (8)$$

IV. RESULTS AND DISCUSSION

The outdoor testing was done on 29th and 30th October 2014 with and without PCM respectively. The flow rate of water was 75 LPH considered for both days. Figure 2shows the operating parameters and observations of the inlet and outlet temperature of the HTF, the ambient temperature, the average receiver surface temperature and the beam radiation were observed without PCM. The flow rate of the HTF was maintained at 75 LPH throughout the experiment. The receiver on this day was tested without the use of the PCM material inside the receiver.

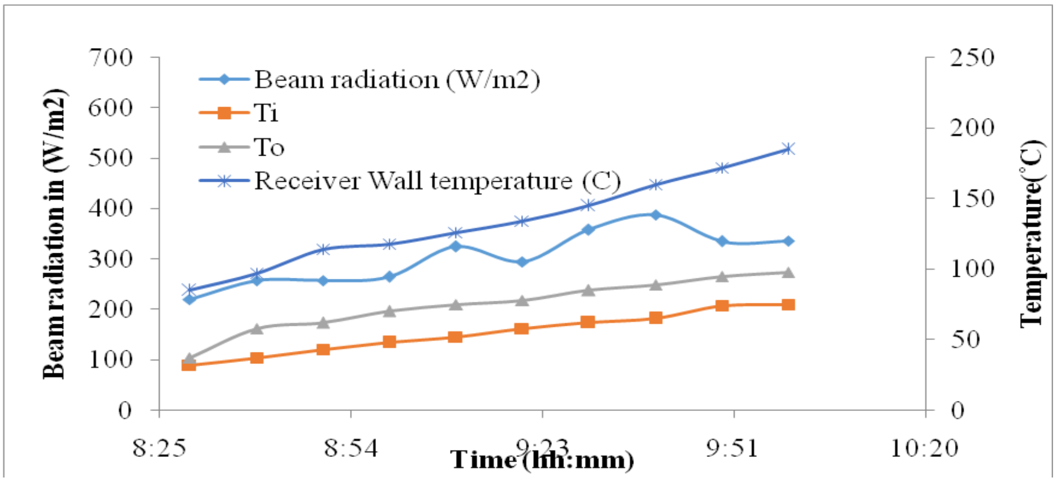

Fig. 2.The variations in the Temperatures and Beam Radiations with respect to time when the receiver was tested without PCM

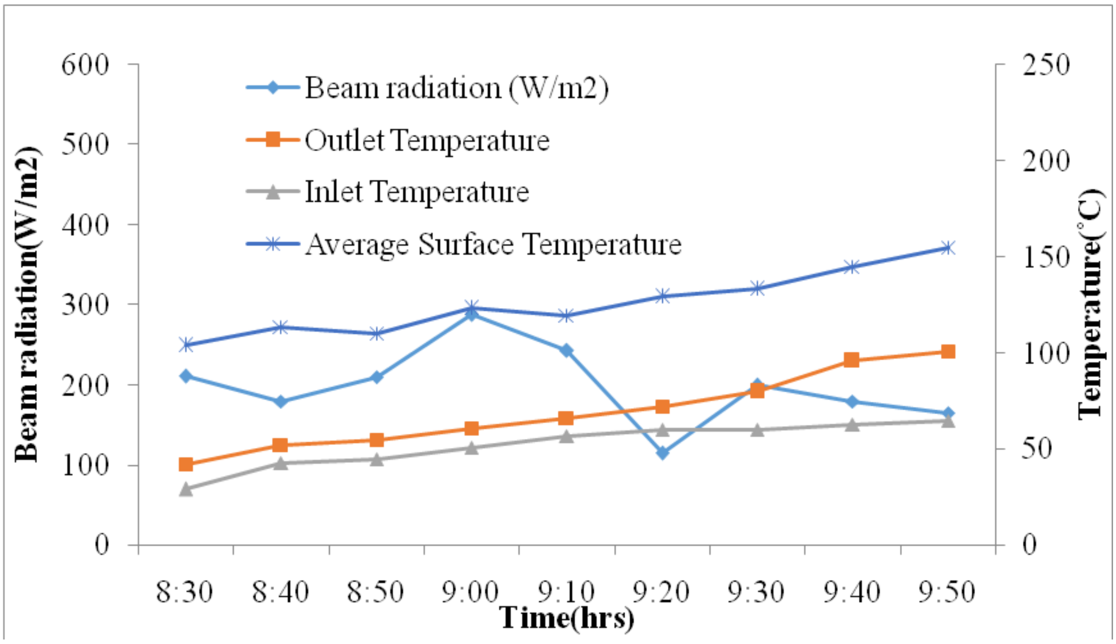

Fig.3. The Variations in the Temperatures and Beam Radiations With Respect to Time When the Receiver was Tested with PCM

Figure 3 shows the readings taken on 30th October 2014 in the presence of the PCM material at the periphery of the receiver. The average surface temperature of the receiver with the use of the PCM material was observed to be slightly lower than that with the PCM. Exergy and energy efficiencies were calculated for the receiver with and without the use of the PCM.

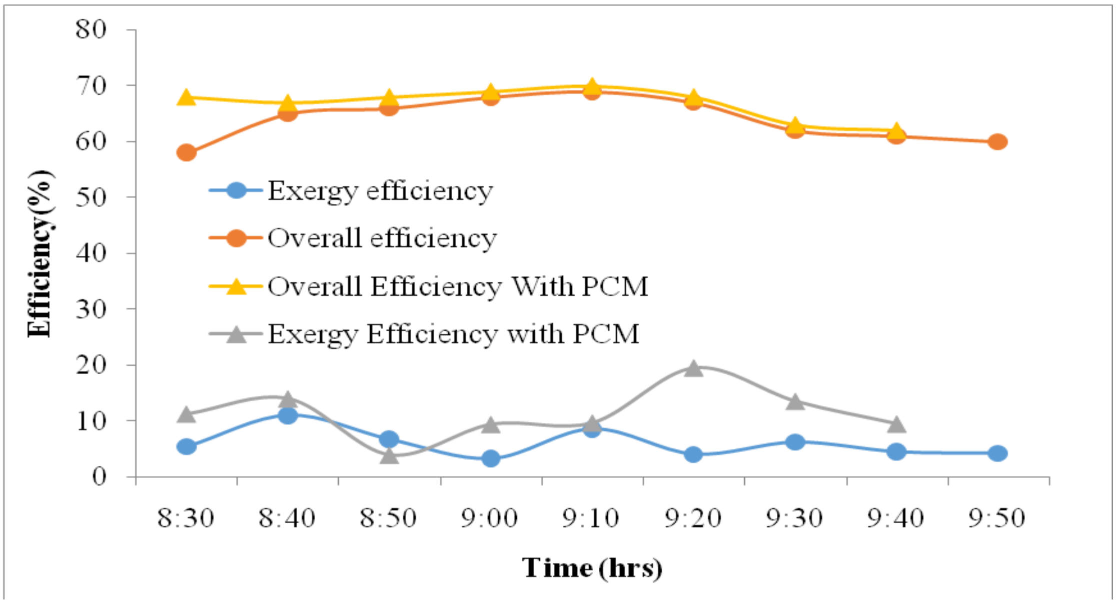

Fig.4. The comparisons of Exergy and Energy efficiency for the receiver tested with and without PCM.

The Exergy efficiency with the use of PCM was found to have a significant increase than the receiver without the PCM material. The average exergy efficiency value was found to be almost twice than that without the PCM material. The energy efficiency curves showed similar trend for both with and without the PCM. The average energy efficiency with the use of the PCM material was found to be 4.7% greater than that without the PCM material.

V. CONCLUSION

The parabolic dish solar receiver was tested with and without PCM to analyse the receiver thermodynamically. It was found that there was significant amount of heat losses from the receiver and these losses can be alleviated using PCM inside the receiver. The operational duration was reduced by 9% to attain the same temperature of HTF in case of receiver with PCM and the energy efficiency was increased by 4.5%. The exergetic efficiency was increased twice that of without PCM case. The improved energy utilization in the receiver has been observed due to lower heat losses from the receiver with PCM. Therefore, this work will contribute to solar collector manufacturers and users for both industrial and domestic applications.

REFERENCES

[1] Kumaresan, G., Velraj, R, and Iniyan, S. (2011)'Thermal Analysis of D-Mannitol for Use as Phase Change Material for Latent Heat Storage', Journal of Applied Sciences, Vol.11, Issue 16, pp.3044-3048.

[2] Tao, R.W., He, Y.L., Cui, F.Q, and Lin, C.H. (2013) 'Numerical study on coupling phase change heat transfer performance of solar dish collector',Solar Energy, Vol. 90, pp.84–93.

[3] Ashmore Mawire, and Simeon Taole, H. (2014) 'Experimental energy and exergy performance of a solar receiver for a domestic parabolic dish concentrator for teaching purposes', Energy for Sustainable Development, Vol. 19, pp.162-169.

[4] Ricardo Vasquez Padilla, Armando Fontalvo, GokmenDemirkaya, Arnold Martinez, Arturo Gonzalez Quiroga. (2014) 'Exergy analysis of parabolic trough solar receiver',Applied Thermal Engineering, Vol. 67, pp.579-586.

[5] Senthil, R., Cheralathan, M., 'Effect of non-uniform temperature distribution on surface absorption receiver in parabolic dish solar concentrator', Thermal Science (2015) doi: 10.2298/TSCI150609169S

[6] Senthil, R., Cheralathan, M., 'Effect of PCM in a solar receiver on thermal performance of parabolic dish collector', Thermal Science (2016) doi: 10.2298/TSCI150730007S

[7] Ramalingam Senthil, Marimuthu Cheralathan, 'Effect of Once-Through and Recirculated Fluid Flow on Thermal Performance of Parabolic Dish Solar Receiver', Indian Journal of Science and Technology, 9 (33), doi: 10.17485/ijst/2016/v9i33/89084.

[8] Duffie, J.A., Beckman W.A., Solar Engineering of Thermal Processes, John Wiley and Sons Inc., New York, 1991.