Effect of Sensible and Latent Heat Materials in the Concentrated Solar Receiver Storage

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Abstract— A cylindrical solid aluminum receiver of 200 mm diameter integrated with phase change material (PCM) and thermic fluid is proposed for parabolic dish concentrated solar collector. The objective is to store the concentrated solar radiation at the point-focus to minimizing the heat transport losses to the storage. Cylindrical cavities of 40 mm diameter are provided inside the receiver to accommodate the oil and PCM. The incident solar energy is stored as combined sensible and latent heat in the receiver. The aluminum and thermic oil stores energy as sensible heat and PCM stores as latent heat. The test was carried out with the receiver with and without storage in the real-time environment. The total energy stored when the receiver reaches 300□ Celsius is around 6 MJ. The receiver with PCM storage serves for longer duration than the receiver without storage.

Key words: Sensible and latent heat materials, concentrated solar receiver

I. Introduction

Most of the domestic applications like hot water, space heating, cooking etc. lies between 60°C and 180°C. The fluctuation of solar radiation leads to incomplete utilization of the solar energy. Several researches are carried out by various researchers for the receiver design and thermal investigations on the receiver [1-5]. Thermal energy storage systems for solar parabolic dish system with temperatures ranging from 250 °C – 500 °C [6]. The enhancement of PCM performance and utilization of PCM in the solar receiver is studied [7-9]. The open and closed circuit of fluid on the solar receiver is investigated by Senthil and Cheralathan [10]. Solar receiver coatings are examined by Sundaram and Senthil [11]. Thermal battery aspect is explored in the solar receiver [12, 13]. The sensible and latent heat materials in a solar cooker and secondary reflectors are investigated [14-18]. The design factors of parabolic dish technologies are discussed by Hafez et al. [19]. Based on the literature review carried out, the investigation of receiver with oil and PCM is done and the results are discussed in this article.

II. Experimental work

An aluminum solid cylinder of diameter and length as 20 cm is used as the integrated receiver-storage. Five cylindrical housings with diameter 4 cm and depth of 18 cm were made in the aluminum cylinder to act as receiver-storage. Multiple pass heat transfer copper tubes of 6 mm diameter and wall thickness of 1 mm) are fitted inside the receiver to retrieve the stored heat. However, the heat retrieval process and the results are excluded in this article. The phase changing materials (Erythritol) was filled in the PCM containers and sealed properly. The thermic fluid is filled in the four housings and made oil leak-proof. The experimental set up consists of solar dish reflector, thermal storage unit with erythritol and oil to act as the receiver as well as storage unit (Figures 1 and 2). The circular surface of the aluminum cylinder was exposed to the solar concentrated beam rays using the Scheffler type reflector with an aperture of 16 m^2 (built by Thermax India Ltd, Pune). The concentration ratio is around 500. The achievable optimum temperature is around 600°C.

The surface temperature of the receiver is allowed to reach the maximum of 550°C for material constraints. The heat transfer takes place from the exposed surface to the other end through conduction heat transfer. The PCM melting takes place inside the receiver and retains the heat by its phase change. A cylindrical Aluminum receiver integrated with latent heat storage system using phase changing material and thermos-oil in a cylindrical cooper container is proposed for concentrated solar collector. Using K-type thermocouples in the cylinder walls, the temperature at predetermined points are recorded to determine the heat stored in the receiver materials. The outdoor testing is conducted on the sunny days in April 2017 in SRM University, Kattankulathur, Chennai, India.

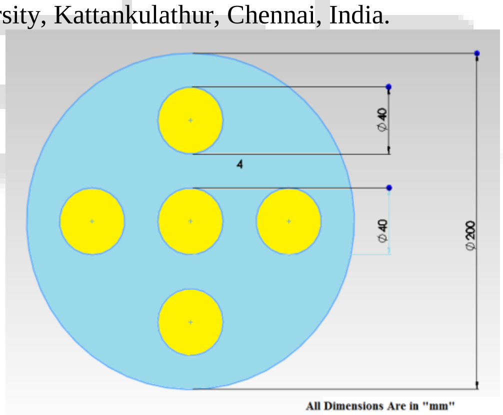

Fig. 1: Model of thermal energy storage

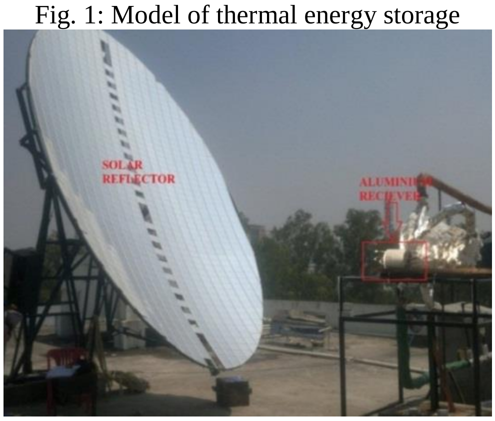

Fig. 2: Concentrated solar collector

Thermic oil	Thermia 66
Density at 20 ºC	1008
Specific heat at 20 ºC	1.6
Thermal conductivity 20 ºC	0.12
Prandtl number	900

Operating temperature	50 - 316 °C
Autoignition temperature	366 °C

Table 1: Properties of thermic oil

Material	Aluminum
Melting point, T_m	660 °C
Boiling point, T_b	2470 °C
Specific heat of Al, Cp	0.91 kJ/kg-K
Thermal conductivity @ 20 °C, k	204 W/m-K
Density of solid @ 20°C, ρ_s	2700 kg/m^3

Table 2: Properties of receiver material

PCM	Erythritol
Melting point, T_m	118 °C
Boiling point, T_b	331 °C
Heat of fusion	339.8 kJ/kg
Specific heat, Cp (l)	2.76 kJ/kg-K
Specific heat, solid, Cp(s)	2.4 kJ/kg-K
Thermal conductivity @ 300 °C, k_l	0.326 W/m-K
Thermal conductivity @ 20 °C, k_s	0.733 W/m-K
Density @ 300 °C, ρ_l	1300 kg/m^3
Density @ 20 °C, ρ_s	1480 kg/m^3

Table 3: Properties of Erythritol

The properties are used to calculate the sensible and latent heat stored in the receiver integrated with the thermic fluid and PCM storage materials are given in Tables 1-3.

Energy stored in Al receiver with PCM

$$= (m\, C_p\, \Delta T/t)_{Al} + [m\, Cp_s\, (T_m - T_i) + m\, L + m\, Cp_l\, (T_m - T_f))/\, t\,]_{PCM}$$

Where, m = Mass of Al receiver in kg = 17 kg
Cp = Specific heat of Al = 0.91 kJ/kg K
$\Delta T = Tf - Ti$
t = Time of operation in seconds
T_m = Melting point of Erythritol in °C
T_i = Initial temperature of Al as well as PCM in °C
T_f = Final temperature of PCM in °C

III. RESULTS AND DISCUSSION

The outdoor experiments are conducted on the receiver with thermic oil and PCM to act as the combined sensible and latent heat storage. The solar radiation, wind velocity, receiver temperature, ambient temperature, PCM and oil temperature are measured at the site. The entire receiver is insulated with glass wool for 50 cm thickness for proper insulation. The trial was taken till the receiver achieves almost uniform temperature around 200 °C.

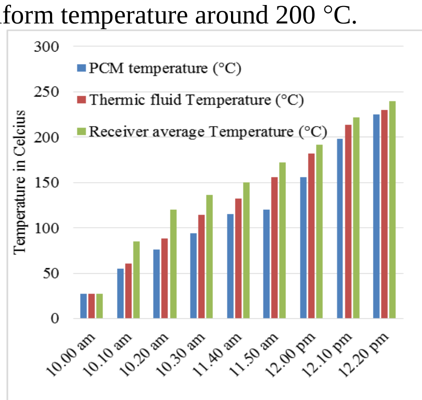

Fig. 3: Temperature trend of sensible and latent heat materials (25th April 2017)

`The physical properties of aluminum and phase change materials were assumed constant during the trial. The charging process was done in 2 hours as the sensible heat for the desired temperature range. Similarly, the charging process was tested for 2.5 hours with PCM filled in the same receiver.

The exposed receiver surface was covered with insulation lid and the temperature history was studied for the storage capability. The PCM filled receiver showed better performance during the trial after 4 hours of storage. The PCM latent heat is utilized after 4 hours and the receiver temperature history showed higher temperatures than the receiver without PCM materials.

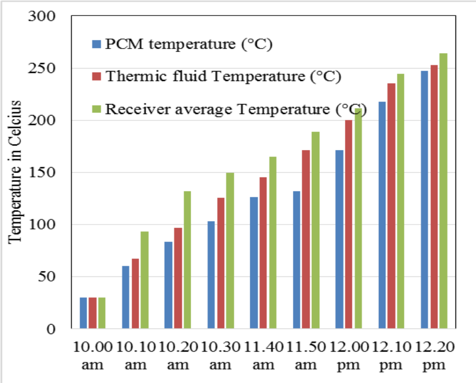

Fig. 4: Temperature trend of sensible and latent heat materials (26th April 2017)

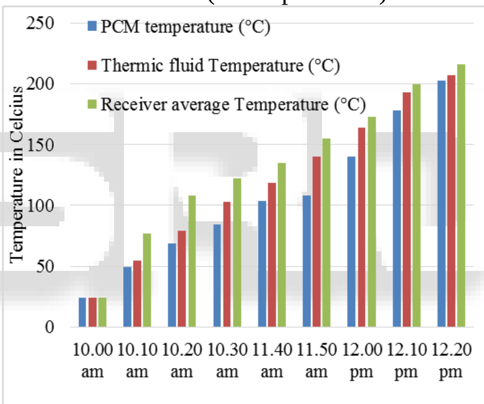

Fig. 5: Temperature trend of sensible and latent heat materials (27th April 2017)

Figures 3 - 5 showed the temperature trends of the receiver material, sensible and latent heat storage materials in the receiver. The testing data are revealing the almost similar operating conditions (Figure 6) and the ambient temperature and wind speed are measured at the site during the testing and they are illustrated graphically with the data in the tables.

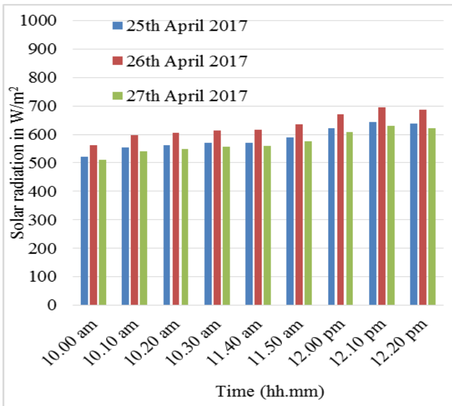

Fig. 6: Solar radiation on the test days

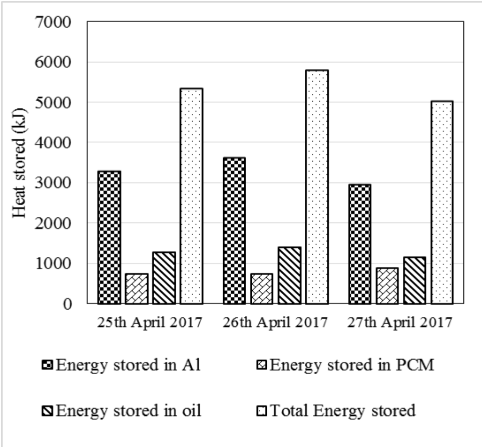

Fig. 7: Energy stored in the solar receiver

The receiver with sensible and latent heat materials is tested on three consecutive sunny days (Figure 6). The total energy stored when the receiver reaches 300° Celsius is around 6000 kJ. The PCM is stored in one of the five housings in the receiver stores around 800 kJ of energy whereas four housings are filled with PCM increases three times of the energy stored in the PCM from Figures 7 and 8.

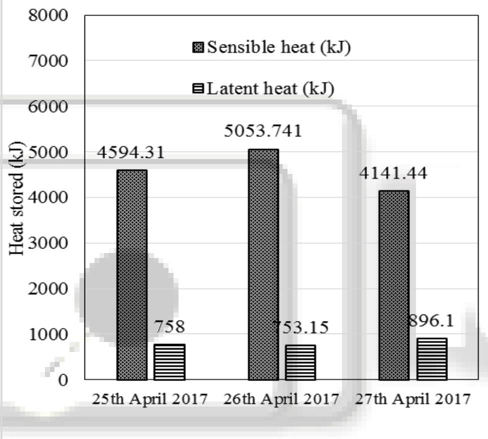

Fig. 8: Energy Stored in the combined sensible and latent heat in the receiver

The sensible heating materials and latent heat materials used in the receiver produces the combined effect on the charging of the receiver.

IV. Conclusions

The incident solar energy is stored as combined sensible and latent heat in the receiver. The aluminum and oil store energy as sensible heat and PCM stores as latent heat. The total energy stored when the receiver reaches 300° Celsius is around 6000 kJ. The oil in the receiver assists the melting of PCM in the receiver. The sensible heat materials like thermic fluids are having higher specific heat capacity and are capable for producing more uniform temperature in the receiver. This sensible heating increases the rate of charging of PCM in the receiver.

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