Experimental analysis of a solar cooker with a parabolic trough enhanced with PCM based thermal storage

S. Babu Sasi Kumar¹, M. Chinna Pandian²
¹Phd Scholar, St Peter’s Institute of Higher Education and Research, Chennai-600 054, India,
²Department of Aeronautical Engineering, St Peter’s college of Engineering and Technology, Chennai-600 054, India,

Corresponding author Email: sbs.kumar1212@gmail.com

Abstract. Experiments are conducted on solar cooker using solar energy. Heat collected by a fluid from the Parabolic Trough Collector (PTC) with the manual Tracking Mechanism(TM) is passed through the Storage Tank (ST) . A Phase Change Materials (PCM) in the ST products absorbed the heat in the irregular sunlight and is released constantly for cooking purposes. Based on the observation of PTC and ST, a heat transfer analysis of the Solar Cooker (SC) is carried out considering 0.035, 0.045 and 0.065 kg/sec Mass Flow Rate (MFR) of the heat transfer fluid. At 1 pm, the maximum Heat Gain (HG) of PTC receiver at the Rim Angle (RA) of 82° is found to be 2095 W, 13 KW in ST with a medium of Wastage Engine Oils (WEO). The heat output of the WEO found to be 16% more than that of the water. The efficiency of the newly designed the solar cooker is tested at the MFR 0.035, 0.045 and 0.065 kg/sec along with storage medium. The results of the MFR of 0.035 kg/sec are seen as better than 0.045 and 0.065 kg/sec for the water and WEO medium. Hence the energy extracted is greater. The WEO is seen as more stable with smaller energy losses than the water. Stearic acid (SA) is used for PCM materials.

1. Introduction

Cooking is a very essential activity worldwide. Many have started using the energy source from liquefied petroleum gas. But, in India, only 70% of population get depend on assets. SE is the only direct precious method as light energy is rehabilitated into heat energy in the Solar Cooker (SC). The SC is the most appropriate, simplest, low charge and mass convenient method of cooking food without any fuel. Employing of SC is the best for rural household in matters of time saving, quality and safety. In this paper, I like to discuss about energy analysis of PTC-receiver, ST and CV.

Michael DiGrazia et al made an alternative solar reflector sheet of a light weight, lower cost and with durability of a polymer layer with the lamination aluminum sheets of different sizes [1]. Govindaraj et al investigated the thermal performance of PTC assisted with storage system. The result showed an increase in the incident of the beam radiation causing increase an instantaneous efficiency [2]. Senthil et al did experimental work based on thermal performance of the PTC for useful energy and heat removal factor. The conclusion was that the increase in low flow rate, the concentration ratio causes increases in
the thermal efficiency of PTC [3]. Mohammed Hadi Ali et al experimented on the focal length of 47.02 cm based on the planned and fabricated the PTC and obtained a maximum temperature of 90°C at an ambient temperature of 30°C [4]. Vinayak et al. investigated work based on the PTC receiver coil. They obtained maximum temperature 160°C and its working medium water outlet temperature was increased by 50% compared to the heat losses will be 20.25% of the receiver [5]. Mohamed et al did analysis of the heat losses from PTC and have suggested that the difference between the working fluid and ambient temperature increases the temperature losses. This could be of use as higher temperature significance to reduce heat losses by using a single cover for the collector of length 10 m or less and could be more economical than a double glazing tube [6]. Atul et al. effect based on with and without glass cover for the PTC receiver made of fiberglass-reinforced plastic, is found that the instant efficacy of 51% and 39% with and without glass cover [7]. Jiangfeng et al. investigated the performance of the PTC receiver under different parameters like a mass flow rate, atmosphere temperature, incident angle and losses. They concluded that energy loss of solar receiver increases as the inlet, with increase in wind velocity inner diameter and the convective heat loss of glass cover. [8]. Recordo et al. analyzed PTC receiver model, the measured techniques for the computation of heat losses and TE under varying MFR [9].

Panwar et al. investigated the initial and exit energy of the solar cooker at different applications. They found SE as the best energy source for cooking [10]. Nelson et al. investigated the photo voltaic system that adjusts the double axis TS which produces more energy output compared to the absence of a tracking system. In cloudy conditions, the output of solar energy with tracking system decreases [11]. Evangelos Bellosa et al. investigated the initial and exit energy performance of the PTC for various storage tanks sizes of 3m³ to 15m³. The storage tank of the 9m³ obtained medium efficiency of 37.1% and 68.7% respectively in the months of the December and June [12]. Sarayooth Vaivudh et al. investigated TES for a charge process. The increase in the stored energy temperature depended on Transfer fluid temperature, flow rate and initial temperature [13]. Amirham Valan et al. did experiment work on the well mixed recirculation water through a closed loop hot water storage system. The work showed increase in the TES temperature from 35°C to 73.84°C at the interval of 9.30 am to 4.00 pm during the period with the average solar radiation at 699 W/m². Observation was made every hour to evaluate the instantaneous efficiency of the collector water gain temperature, useful heat gain and values were obtained maximum at around noon [14]. Jinjia Wei et al. did work on the four different capsules (sphere, cylinder, plate and tube) to observe the phase structures of PCM. The effect of the capsule
diameter and the void fraction on the shell width and TES performance were studied. The spherical capsule energy output and efficiency increased during the use of four categories of the investigation [15]. Menakshi Reddy et al did experiments based on the TES using PCM. The outcome showed at almost the same output for the Stearic Acid (SA) PCM and Paraffin wax PCM but the SA was less expensive [16]. Kumarasan et al experimentally investigated the thermal property of PCM in the LHS system. From the experiment showed phase change in the melting point at beginning, peak and enthalpy [17]. Ismail et al analyzed a numerical model for the packed bed in sensible and latent heat storage systems. The models compared the objectives of the control factors like a particle size, shape, the component material, the flow rate variations, the working fluid temperature, and the wall temperature losses [18]. Sharma et al experimented on the commercial-grade SA, acetiamide and paraffin wax PCM. During the charging process the melting temperature and specific heat of PCM were observed. SA was seen with constant phase change substances than the erythritol–PCM during the charging process has helped conclusion from solar cooking model of ETSC with PCM system. The PCM unit stored energy in daylight and cooking was done at night. The procedure was continuously implemented into the system of the solar cooking and energy obtained at night was higher than daytime cooking [19]. Kamal et al tested the phase change properties of the TES. The simple method has been briefly explained the energy factors such as radial temperature flow, phase change property and heat absorption are discussed at different flow rates [20]. Mawire et al did investigation of a simulation model of oil/pebble-bed TES which stored energy utilized for indirect solar cooking. The outcome proved a variable flow rate as suitable for cooking purposes as it absorbed a large quantity of heat, producing lower heat loss and could withstand a high temperature for more than an hour [21]. Mawire et al., (2010) simulated the analysis of the initial and exit energy of the solar cooker carried out using two variable flow methods. The result demonstrates the continuous maintenance of the variable flow rate at a higher temperature compared to a constant flow rate [22].
2. Experimental investigation

A photographic view of the experimental setup for SC from the PTC assisted PCM heat storage is shown in figure 2.1. The setup consisted of two paths. Initially the transfer fluids (wastage engine oil & water) in the TES were at room temperature. This TF was pumped into the PTC receiver through the check valve for absorbing heat from the receiver and its energy was stored in the ST. The other path considered was of the stored heat transfer fluid in the ST pumped into the cooking oven for cooking purposes using the check valve. Once its utilized energy fluid was pumped back into the ST, the process was continued.

The objective of the research work is to make heat energy utilized from the fabricated PTC of the total space area 4.5 m² and made up of aluminium foil reflected sheet for absorbing and reflected the sun’s rays focused on the receiver coil for transmitting light energy into TE by thermic fluid. The PTC receiver consisted of the stainless steel tube, vacuum glass tube, bushes and support plate. The
glass tubes with one end inlet opening and the other end was sealed. Outer and interior tubes of absorber had 0.051 m and 0.043 m diameter and length (cover tube) 3 m correspondingly, the thickness of the tube was 0.4 m as shown in figure 2.2 and its specifications as shown in Table 1.

![Photo view of the Receiver Tube](image)

The inner tube-exterior surface was coated with the black paint for increasing the absorption of SR and its absorbed heat was stabilized from the air to avoid heat losses and the gap between the two tubes was sealed. The solar radiation of heat energy absorbed was converted into thermal energy by the receiver tube circulating fluid.

**Table 1 PTC receiver specifications**

| Item                      | Value/Type     |
|---------------------------|----------------|
| Collector aperture area   | 5.04 m²        |
| Aperture width            | 2.8 m          |
| Receiver diameter         | 48 mm          |
| Tracking mechanism type   | Manually operated |
| Mode of tracking          | Single-axis    |
TS were useful for continuous projection of reflected sun radiation on the focus path of the PTC. It consisted of the movement of the trackers which can have either a horizontal or an upright axis controlled by using the big worm gear supporting the rotating in the direction opposition to that of the worm as shown in the figure 2.3. The rotating worm was fixed in the coupling bush of the supporting frame. TE was used for increasing the output influence of the PTC by making the SR of the beam which focused into the receiver tube equal to zero geometrical losses. The operation of the TS system for monitoring the change in the position viewpoint in the receiver was done every 3 minutes. The related costs, comfort design, performance and movement capability to fabricate in the manual tracking system.
Figure 2.4 Rectangular PCM boxes are arranged in the ST

The rectangular shape of the cooker consists of a semicircular shape stainless steel plate is placed on the top side, for cooking the foods as shown in the figure 2.5. The bottom side of the oven is entirely covered
with soldering copper coil on all sides to absorb the heat in all sides and its entire structure is insulated with the glass wool about thickness of 0.05m.

Fig 2.5 Photo view of the Cooking Vessel

Instant temperature is measured at various locations by using K-Type thermocouples. A pyrometer is a device actually tracks and measures the amount of heat that is radiated from an object. The thermal heat radiates from the object to the optical system present inside the pyrometer. The optical system makes the thermal
radiation into a better focus and passes through the detector. The output of the detector will be related to the input thermal radiation. From the experiment using a MasTech (MS6610) Luxmeter. These Sensors are connected to a computer through a data logging system, which stores the outputs and records data for 30 seconds. A thermal bath, motor, pump and control valves are connected in the pipeline for charging and discharging of the PCM storage system. Here, wastage Engine Oil and Water is used as Sensible heat and PCM as a latent heat medium. Water is non-hazardous and cheapest substance. Its belongings of the specific heat, freezing point are high where its viscosity and boiling point is low. WEO becomes less viscous as it gets hotter and lubricates better and resist vaporization. SAE 10W-304-AT multi grade oils are to operate over a wide range of temperatures, so that the ambient conditions may not reach high thermal states. The efficacy of the SAE 10W-304-AT is really dependent upon the heating rates, specific heat capacities and the viscosity of the oil samples. These properties are stronger to operate at high temperatures conditions and also it provides an excellent protection against corrosive wear. The oil is suitable for all the reasons and retains in the high level of alkalinity and is used for operating cold starting and humidity condition. The experiment is conducted for different mass flow rate such as 0.035 kg/sec, 0.045 kg/sec and 0.065 kg/sec for various components of the inlet and outlet of the PTC receiver, the storage tank, the cooking vessel and PCM storage tank temperature.

3. Formula to be used:

(i) Mass flow rate of the working fluid

MFR is defined as the mass of a liquid substances passing per unit time is called as mass flow rate and is related to Volume flow rate.

\[
\text{MFR} = \frac{\text{Mass in kg}}{\text{time in second}} = \frac{\text{volume in litres}}{\text{second}}
\]

(ii) Thermal Efficiency (TE) of PTC:

The TE of the PTC can be simplified and defined as the ratio of useful heat \( (q_u) \) delivered per Surface Area \( (A) \) and the \( I_{Sas} \) intensity of solar radiation \( (SR) \) of the surface.
Thermal efficiency \( \eta \) = \( \frac{q_u}{A I} \) \tag{1}

and Heat gain \( q_u \) = \( m c \ p dT \) in Watts \( \tag{2} \)

Surface area \( A \) = Width x Length in \( m^2 \)

Where \( m \) is mass flow rates of working fluid in kg./sec

and \( I_p = \) Intensity of solar radiation in Watts \( m^2 \)

(iii) Useful energy output for the load of ST

\[ q_{\text{useful}} = \rho V_{\text{st}} c_p \Delta T \] \tag{3}

Where \( \rho \) is the density of the working fluid, \( V_{\text{st}} \) is the volume of storage tank, the specific heat of working fluid as \( c_p \) and \( \Delta T \) is the different between the ST outlet and inlet temperature in °C.

(iv) Utilized energy output for CV at an MFR of water

The General equation of useful heat gain is

\[ Q = h A (T_w - T_a) \] \tag{4}

Where \( h \) is heat transfer coefficient in W/m²K, Surface area A and \( T_w, T_a \) are temperature of working medium and air respectively.

\[ T_e = \frac{T_w + T_o}{2} \]

The Reynolds number

\[ R_e = \frac{V D}{\nu} \]

Where \( V \) for velocity of working media and \( D \) is diameter of copper tube and \( \nu \) iskinematic viscosity of medium.

The Nusselt Number

\[ Nu = \frac{c (Re)^{m} (\nu)^{0.333}}{D} \] \tag{5}

Average heat transfer coefficient \( h = \frac{Nu k}{D} \) in W/m²°C

(v) Utilized energy output for CV at an MFR of WEO

The same procedure as to follows the water medium but Nu as calculated by using formula
since \( Re > 2300 \) flow is turbulent

\[
\frac{L}{D} = \frac{1.3}{0.02} = 65
\]

\[10 < \frac{L}{D} < 400\]

\[ Nu = 0.036 \left( Re \right)^{0.8} \left( Pr \right)^{0.333} \left( \frac{L}{D} \right)^{-0.055} \]  

4. Result and conclusion:

The experimental test was conducted in the months of February, March -2018. The designed model, geometric dimensions, geometric angles of the PTC and the Rim angle at different position of the TE and Heat gain for PTC, ST and SC and addition of PCM Storage Tank at the effect of the different MFR have been discussed. The specific heat of TF of water was seen as more than that of engine oil reflecting the variations in the efficiency and energy output. The stored energy of wastage engine oils was compared with that of water, the boiling point temperature of WEO was seen as 400°C whereas the boiling point of water was 100°C, which is the fact. Hence so water got evaporated above the temperature of 100°C but the WEO stored more energy as it evaporated above 350°C.

4.1. The Performance TE of the Rim Angle

The experiment started at 9.00 am with RA 15° and TE of 33%. When it reached 11 am, the RA was 38° at TE of 53% whereas, at 12.00 noon the, RA was 60° and TE of 69% and increased continuously depending on increase in SR. It reaches high efficiency at 1 pm, the charging efficiency of WEO at 82° RA was 78%, greater at 1 pm, after 2.00 pm it was 95° RA. There was a decrease in WEO efficiency to 75.8%. The energy was computed using equations 8 and 9. There was a decrease in the approximate constant efficiency of PTC from 1.00 pm to 2.00 pm due to the proportionate increase in the heat loss, as the energy was removed from the ST instead of being stored. Hence at 3.00 pm at 115° RA the TE decreased to 67% as the solar radiation decreased and the heat loss increased
Figure 4.1 TE versus Rim Angle of the PTC

Figure 4.1 confirms if RA as the best, TE was augmented up to 1pm and the value diminished later. At 82° RA maximum efficiency of WEO obtained was 78.7%, 75.2% and 72% for an MFR of 0.035, 0.045 and 0.065 kg/sec and 67.8%, 62.4% and 59.4% for water respectively and the performance WEO was 16%, 20% and 21% times more than that of water.

4.2 Comparing Heat gain of the PTC receiver at an MFR

Evaluate of the performance of the variation in HG of the PTC receiver with respect to time was done evaluated using the 2. At the beginning the PTC receiver temperature was increasing at a lower rate, due to the thermal inertia correlation with the system devices.
Figure 4.2 Comparing Heat gain Vs Time at an MFR the PTC receiver

Observation at 9.00 am showed the variation in ambient as 19.6°C and the intensity of the SR as 452 W/m². There was an increase in radiation up to 590 W/m² at 1 pm. The effect of increase in the concentration ratio was high, the losses from PTC receiver showed decreases, the difference between the outlet and the inlet temperatures increased faster rate at noon due to the intensity of increase in SR and thus increasing the collection of useful energy. However, after 1.00 pm and up to 2.00 pm temperature slowed down from the peak due to a decrease in the SR. Peak efficiency was attained at 1.00 pm by which time the HG of receiver tube temperature increased. After 2.00 pm, the PTC temperature decreased due to a decrease in the system efficiency related to the increase in heat loss coefficient by convection with increase in the receiver temperature. This has been justified by Steven Boltzmann law. The result indicated a decrease in the efficiency of the receiver due to the difference in the receiver and the ambient temperatures and absorbed by employing fluid stored in the storage tank. The above discussion shows increase in the HG where by SR increasing the TF. The variation in HG increase depends on the increase in heat removal factor. After this hour, the solar radiation rate decreased and at the end of 4.00 pm it was 480 W/m².

At 1.00 pm with the maximum intensity of 590 W/m² solar radiation with 104.9°C of PTC, the Heat Gain(HG) was 1802 W and TE was 67.2% for water, for WEO when PTC receiver was 122°C, HG is 2095 W and TE was 78.7% respectively which was 16% higher than water. In the MFR 0.045 kg/sec
the HG of PTC receiver is 1658 W for water, for WEO when the HG receiver is 2095 W. Thus its output is 20% more than water. After 2.00 pm its values decreased due to the absorption of heat by the working fluid passing through PTC receiver. Thus changes in SR occurred resulting in increase in the temperature of outlet working fluid based on the PTC receiver surface at the similar time due to the losses associated with an increase in environmental factors. At the MFR 0.065 kg/sec the HG is 1578 W in water medium while HG is 1904W respectively in WEO medium. The experimental value of the energy output of the WEO is 21% is shown as greater than water. However, this output is less compared with MFR 0.035 kg/sec because of the flow rate and heat losses is more in the TF.

4.3 Comparing Thermal Efficiency of the PTC receiver at an MFR

Figure 4.3 shows that, at 1.00 pm with the MFR 0.065 kg/sec PTC receiver the TE in water is 59.4% while in WEO it was 72%. The MFR of 0.045 kg/sec PTC receiver the TE in water was 62.4% and in WEO was 75.2% but in the MFR of 0.035 kg/sec PTC receiver the TE of water was 67.2% and WEO was 78.7%. Thus output, shows TE of MFR 0.065 kg/sec as less compared to the usage of MFR of 0.035 and 0.045 kg/sec due to high flow rate, environmental factor and the overall heat transfer coefficient. The instantaneous efficiency of the PTC increased from 33.8% to 46% during
the time interval between 9.00 to 10.00 am, after that there was a further increase at a faster rate until noon, and then it started decreasing. The instant efficiency of the PTC depended on both the incident SR and the HG and these two factors were more favourable during the time interval for increasing the collector efficiency.

4.4 Comparing the Performance of the ST in a transfer medium

The focus of the experiment is on the development of the energy output of the storage medium. ST which contains 16 numbers of SA PCM rectangular boxes arranged for testing under at MFR 0.035, 0.045 and 0.065 kg/sec respectively. The performance outputs of the ST during the charging and the discharging processes were determined using equations 8 and 12. At the initial stage PTC receiver, TF and ST were approximately at room temperature. After a few minutes and with an increase of convection heat from SR, storage tank temperature increased. The stored energy continued to rise up to 1 pm and decreased slowly till 3 pm. After 6 pm and without SR, heat was removed from the atmosphere and there was a rapid reduction.

TF absorbs heat from PTC receiver and exchanges the energy through PCM boxes in the charging process. The temperature of the PCM inside the rectangular box was lower than that of the melting point range, TF acted as sensible heat. In the stage of the charging process, the PCM sustained a constant temperature for a few hours. Finally the PCM got superheated and its stored energy was transmitted into a sensible heat of TF. The charging process continued till the ST temperature reached the maximum value of 110.8°C due to increased attainment of more than the atmospheric temperature difference and average heat loss per hour at noon and approximately 793 kJ/sec which increased the overall heat transfer coefficient.

When the ST reached 100°C, the overall heat loss coefficient for temperature range was 120°C to 60°C. The ST temperature decreased slowly from 1:00 pm to 3:00 pm is at regular intervals of time with its variation in the corresponding values of overall heat transfer coefficient approximately from 1.5 W/m²K to 1.0 W/m²K.

In the Figure 4.4 shows at 1.00 PM, at a flow rate of 0.035 kg/sec the ST output is 10237 W for water and 13655W for WEO and the energy is 1.33 times higher than the water. The comparing output of ST in water is 5.67 times and WEO is 6.5 times more than the PTC receiver at a flow rate 0.035 kg/sec. With a flow rate of 0.045 kg/sec at 1 pm of the PTC receiver HG heat of 1430 W is obtained.
for water and 1953 W for WEO but in the ST it is 9987 W for water, and 12696 W for WEO medium respectively. This HG is 6 and 6.5 times higher the PTC receiver for water and WEO medium respectively. Similarly, for the useful heat output for the ST at the MFR 0.065 kg/sec of WEO and water mediat 1.00 pm the achieved output power in ST is 9370 W, 12376 W and the energy is 5 and 6.5 times higher than the PTC receiver temperature of water and WEO medium respectively. After fall in SR, the storage EL for the ST is 1.08, 1.14 time each and every hour in both the water and WEO medium.

From the outcomes studied in detail and during the first 3 hours of operation, the stored energy increases due to the increase in the temperature of the flowing path of the transfer fluid in the PTC receiver and PCM ST. After 11.00 am, when the temperature of the TF reaches above 75°C approximately during the charging process for the medium of the WEO. Hence its energy is increasing continuously up to 1.00 pm with the rate of energy accumulated approximately increases SR. At 3 pm to 5 pm, each and every an hour 0.9 times Energy Losses (EL) appears in the ST and after 6-8 pm each and every an hour there is 1.1 times increases EL.

The rate of the energy storage is less when compared to the MFR of 0.035 and 0.045 kg/sec. The higher flow rate is engrossed when heat is draw out of the flow path and the increase heat loss is due to the environs. Therefore when the heat transfer coefficient is less PTC outlet also decreases.

![Figure 4.4 comparing the performance of the ST versus Time](image-url)
Figure 4.4 is highly helpful for evaluation of the energy output of the WEO and water. At an MFR of 0.035, 0.045 and 0.065 kg/sec of the WEO strength was 1.33, 1.22 and 1.32 times higher than that of the water. Further the WEO was the best for maintaining heat constantly for the charging and the discharging processes. At 9.00 am in the MFR 0.035 kg/sec the charging energy acquired was 27% more than 0.045 and 0.065 kg/sec respectively due to the smaller amount of flow rate occupied under a larger absorption of radiation. It also reduced the environmental losses and increased the ST temperature. The experiment showed, the total charging time of the PCM material as 25% to 35% before raising the melting temperature and 20% to 25% following a rise. Therefore, the time taken for melting the PCM material of the SR was around 40% to 50% approximately.

4.5 The Presentation of the ST PCM at a different MFR

The measuring temperature allocation of the PCM rectangular box was split into six segments in the ST at x/L =0.15, 0.3, 0.45 to 0.9 meter respectively. Where L was the length of the ST in meter and was equal to 1 meter, x is the axial distance from left to right of the ST in meter and x/L is the dimensionless axial distance from the left side of the ST system. The K-type thermocouple was placed at a specific location from left to right in the ST for measuring the temperature distribution. From the beginning of the experiment, the charging temperature distribution of the ST was varied from 38° to 57°C from the right to left side and vice-versa respectively. The heat distribution of the ST was studied before for finding the behaviour of TF. An increase in the temperature of the TF in the time gap of 9.00 to 10.00 pm through the heat gained by the PTC receiver was due to the high thermal inertia related to the various components of the experimental setup. After 10.00 am, there was a sharp increase in the temperature of the TF in the ST till 1.00 pm. This decreased at a slower rate up to 2.00 pm, after which there was no further increase in the TF heat for a period of one hour and then it started decreasing.

Let’s us see from the figure 4.5 during the time interval between 10.00 am and 1.00 pm, the heat addition to the ST from PTC receiver was very high. It caused an increase in the thermal stratification between the left to the right portion of the ST. After 1.00 pm and up to 2.00 pm, the temperature distribution in the storage tank slowly decreased after 2.00 pm to 3.00 pm the charging temperature of the ST decreased quickly due to a decrease in the SR and the heat losses in the receiver due to
atmospheric condition. Later, at 3.00 pm, there was a decrease in the output energy and the average temperature of the fluid in the ST due to the density difference between the separations of the segments from left to right side of the ST. The thermal stratification between the top and bottom of the ST caused a reduction in PTC receiver temperature, SR and heat loss in RT. Figure 4.5 presents the temperature variations in ST PCM during the charge and the discharge processes for the MFR 0.035 kg/sec. SA acted as the PCM. There was a gradual increase in the PCM temperature at the beginning, at 11.00 am it reached average melting point of 69°C during which time the PCM charging was constant for half an hour and, thereafter, the charging increased sharply to attain an average TF temperature of 77°C. The charging process in the PCM segment was continuous for completing the 90% charge in all positions and the temperature in all divisions of the PCM reached an average of around 100°C, at the moment TF increased the average to around 105°C.

At division 2 (x/L=0.3) in the opening instant, total heat transfer of the PCM depends on the temperature of the TF alone. During sensible heating of solid PCM, the temperature of both TF and PCM got a boost at a faster rate and its difference got augmented continuously until the PCM reached the melting temperature of 69± 1°C, and the arranging process continued to reach melting temperature and the PCM heat reached was higher than TF. When the particular stage was reached, the entire heat in the TF was transferred to PCM by convection. The same procedure is followed by
another segment PCM also. After the completion of the melting process, The TF and PCM temperature continued to increase until the PCM reached the average 120°C for WEO medium. The above study shows an increase in the storage temperature of the PCM due to the convection of TF and intensity of SR. The change in the time during the charging and the discharging processes for the water medium was not gradual but was constant in the WEO. The stored average energy of WEO was 1.15 times higher than the water medium.

4.6 Comparison of the Heat gain for SC at an MFR

The figure in 4.6 illuminated the CV utilization of the energy output at the different flow rate of the water and WEO and its output energy is computed by using the equation 4 to 6. SC outputs in the water medium were 1.02, 1.17 and 1.43 times lower than the ST at an MFR of 0.035 kg/sec, 0.045 kg/sec and 0.065 kg/sec respectively due to energy losses that happened in the atmosphere. But output in WEO was 1.06 times less than ST and this EL was continuously constant. Figure 4.6

![Figure 4.6 Comparison of Heat Gain Vs Time for CV at an MFR](image)

It shows that, in the WEO medium and at a rate of 0.035 kg/sec in the SC during 6.00, 7.00 and 8.00 PM, the outputs produced were 10003, 8502 and 6537 W and its rate of 0.045 kg/sec produced output were 8031, 7036 and 6211 W respectively. Similarly for an MFR of 0.065 kg/sec the
generating output were 7698 W, 6754 W and 5966 W respectively. Furthermore between 6.00 pm and 8.00 pm, the energy utilized by SC in WEO medium was 1.5 times more than the water.

5. Conclusion

This study made experimental model analysis for a solar cooker from parabolic trough collector assisted by Phase Change Materials for heat storage. Based on these aspects, Heat gain, Thermal Efficiency of the Parabolic Trough Collector-receiver, Storage Tank and Solar cooker at a mass flow rate of 0.035, 0.045 and 0.065 kg/sec were studied and outcomes are presented.

i. Increase in the solar intensity of radiation causes increase in the PTC receiver parameters like output temperature, Heat gain and Thermal efficiency are increases.

ii. The performance of the solar cooker energy output is based on various parameters like mass flow rates of transfer fluid and PCM heat storage.

iii. MFR 0.035 kg / sec is preferred to 0.045 and 0.065 kg / sec for Water and Wastage engine oil, as per the heat energy output.

iv. The Wastage engine oil is also seen as better for steady flow and energy loss than the water medium.

v. The RA of the PTC at mid position achieved a maximum HG, TE at a MFT due to an increase in the high reflectivity of radiation and outlet receiver temperature.

vi. The maximum output of the PTC receiver for WEO was reached at 1 pm at mass flow rates of 0.035 kg/sec, 0.045 kg/sec and 0.065 kg/sec respectively and the energy was 1.2 higher than that in the water medium.

vii. The energy output of Storage Tank is 6.5 times higher than PTC receiver output of the WEO, while it is 6 times higher for water medium.

viii. In the SC, energy output is less than the average of 1.1 times ST output of the WEO, water medium due to convection, conduction and radiation losses.

Abbreviations

CV Cooking Vessel
HG Heat Gain
MFR Mass Flow Rates
PCM  Phase Change Materials  
PTC  Parabolic Trough Collector  
RA  Rim angle  
RT  Receiver Tube  
SA  Stearic Acid  
SC  Solar Cooker  
SR  Solar Radiation  
SE  Stored Energy  
ST  Storage Tank  
TE  Thermal Efficiency  
TF  Thermic Fluid  
TES  Thermal Storage System  
WEO  Wastage Engine oils

**Nomenclature**

- **A** Surface area, m²
- **D** Receiver tube inner diameter, m
- **Cₚ** Specific heat of pressure, Jkg⁻¹℃⁻¹
- **dT** difference in temperature, °C
- **h** heat transfer coefficient, Wm⁻²K⁻¹
- **Iₛ** intensity of radiation, Wm⁻²
- **k** thermal conductivity, Wm⁻¹K⁻¹
- **L** Length in m
- **m** mass flow rate, kg/sec
- **Nu** Nusselt Number
- **Pr** Prandtl number
- **Q** Utilized heat gain in W
- **q_U** heat gain in W
- **Re** Reynolds Number
- **T_w** Working medium temperature, °C
- **T_a** Temperature of air, °C
- **V** Velocity of working medium, m/sec
- **Vₜₜ** Volume of Storage tank, m³
- **ΔT** Temperature difference, °C
- **ρ** Density, kg m⁻³
- **ν** Kinematic viscosity, m² s⁻¹
- **ηₜₜₜ** Thermal efficiency, %
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