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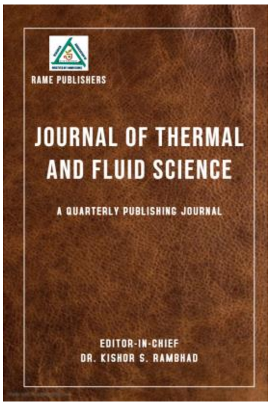
Design and Development of Solar Tiffin Warmer with Thermal Storage

Chirag Kale*, Arya Babu, Dushyant Patil, Deepak Prasad, Yash Thakare

Department of Mechanical Engineering, St. John College of Engineering & Management, Palghar, India

***Correspondence:** chiragk@sjcem.edu.in



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Abstract: An innovative solar-powered tiffin warmer with built-in thermal storage is suggested in this research. Storing food for long periods of time is difficult in many areas of the world due to a lack of electricity, particularly in developing regions. People that depend on pre-packaged meals, such employees, students, and tourists, are especially affected by this problem. sun tiffin warmers, which use sun energy to keep food at a constant temperature, are one answer to this problem. An efficient heating element, thermal storage, a solar reflecting mirror, a phase change material (PCM), and a small, portable tiffin make up the system. In order to maintain a constant temperature regardless of the weather, the system makes use of thermal storage materials to store any surplus heat energy generated during the sun's peak hours. This creative method not only helps the environment by reducing our dependence on traditional energy sources, but it also offers a long-term solution for keeping food warm. The goal of this project is to provide a green, efficient, and cost-effective way to heat meals when traditional energy sources are unavailable. Solar tiffin warmers with thermal storage could help people in off-grid locations live better lives while also decreasing their environmental impact and boosting sustainability.

Keywords: Solar Tiffin Warmer, Thermal Storage, Efficient, Sustainability, Cost Effective, Renewable Energy

1. Introduction

Keeping home-cooked meals warm and fresh during transit is a constant issue in today's fast-paced world, when individuals are often on the move [1-3]. In every household, cooking plays a significant role. Animal manure and firewood are major sources of cooking energy in rural India, where almost 70% of the population resides [4-7]. Even while they work well for storing food, traditional tiffin carriers don't always manage to keep it at the right temperature for long periods of time. This is particularly true in areas where power isn't always consistent. The solar tiffin warmer with thermal storage is a new idea that this study presents to solve this problem [8–11].

A small and portable tiffin warmer with thermal storage capabilities may be powered by solar energy and kept heated for hours using this revolutionary device. An effective and ecological approach for retaining food temperature during transit has been proposed, which blends sophisticated technologies including solar radiation and phase change material (PCM) [12]. An efficient method to offer a consistent supply of solar heat is to incorporate a thermal storage. Potential thermal energy storage materials, phase change materials are known for their high latent heat and consent charging/discharging temperature. Using a thermal reservoir to store the sun's abundant energy, this technology provides a sustainable and dependable substitute for traditional tiffin carriers. This introduction sets the stage for exploring the design, functionality and potential applications of the solar tiffin warmer with thermal storage [13]. By conducting this research, we hope to promote sustainability and energy efficiency while simultaneously improving the lives of those who are always on the move.

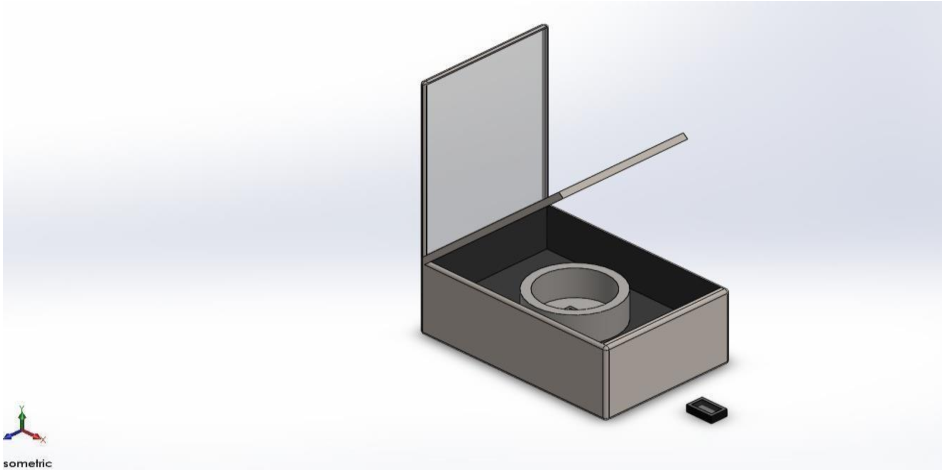


Fig.1. 3D Model of Solar Tiffin Warmer with Thermal Storage

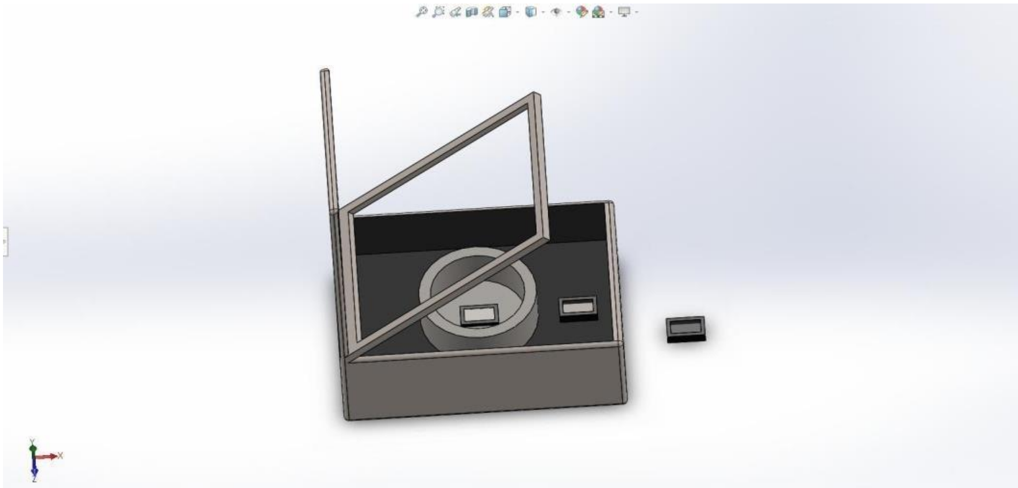


Fig.2. 3D Model with Sensor Placed Inside the Box

2. Literature Review

A survey of the literature on LHTESS: materials, heat transfer, and phase change issue formulation Phase change materials (PCMs) have been the subject of extensive research over the past three decades. This paper provides a comprehensive overview of their development, including the different PCMs studied, the heat transfer and enhancement techniques used to charge and discharge latent heat energy, and the formulation of the phase change problem. It also takes a look at the PCM container layout and design, as well as a battery of experimental and computational studies done to measure the impact of variables like HTF mass flow rate and input temperature. A majority of the phase change experiments have been conducted at temperatures that are appropriate for use in home heating systems, it has been determined. It has been standard practice to employ enthalpy formulation when posing problems. The phase change problem has become more complex as a result of the inclusion of convection in the melt, which was not considered before when the heat transfer was defined using a pure conduction technique.

This paper details numerical studies on a heat storage that makes use of sodium acetate trihydrate (SAT) as a phase change material (PCM). The goal is to optimize the design of this heat storage and release its latent heat. Utilizing the steady super cooling of SAT allows for the use of the heat storage in both the short and long term. There is 75 liters of water and 137.8 kilograms of PCM in the locker. A verified computational fluid dynamics (CFD) model was used to analyze the heat storage flow conditions. A dispersion of flows inside the heat storage that was not uniform was found. There were three different optimization techniques for the design that were considered in an effort to level out the flow. Charging duration, charged heat, thermal stratification degree, and heat storage mixing were among the primary performance metrics used for analysis. It was shown how the thermal performance of the heat storage was affected by the flow direction, input size, and the addition of a porous plate. By reversing the flow direction and inserting the pipe into the upper part of the storage, we were able to cut the time it took to melt the PCM in half. The optimal layout for the storage facility was found.

Scientists conduct an experiment to determine how sodium acetate trihydrate phase change materials reduce latent heat. In terms of thermal energy storage, sodium acetate trihydrate (SAT) phase change materials (PCMs) have a stellar reputation owing to their abundant resources and high latent heat. Latent heat reduction is a major issue for SAT following cycles of heating and cooling. Thickeners have been shown to efficiently prevent reduction in a few earlier studies, but the mechanisms of both the reduction process and their inhibition have not been thoroughly investigated till now.

2.1 Innovation Gap

Currently, the thermal storage which is available cannot last for longer duration, to improve the same we are improvingcapacity and efficiency of thermal storage so that it could last for longer duration.

2.2 Problem Definition

The problem definition involves the absorption and utilization of solar radiation energy to warm the food so that we caneat fresh & healthy by using renewable energy.
Many of the workplace uses electronic oven which consumes more electricity and it is expensive.

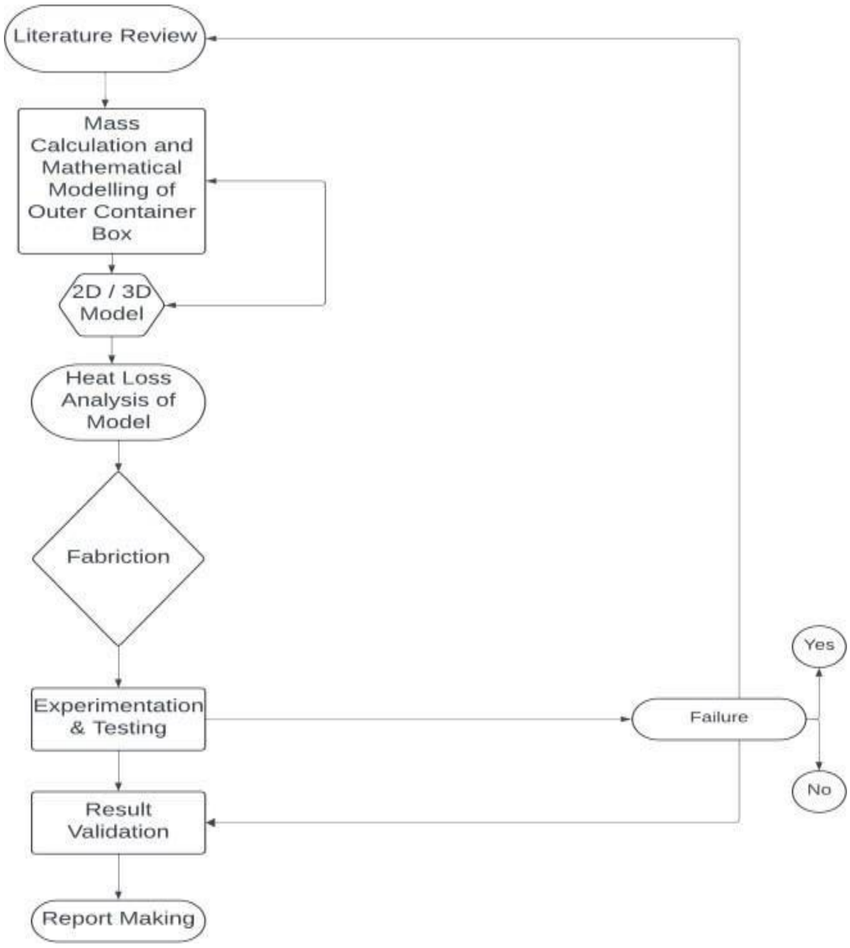


Fig. 3 Methodology Flow Chart

3. Mathematical Modelling Equation

$Q_{Cooking}$ (Rice) = m×cp×Δt (1)
= 0.5×2.930× (60-25)
= 51.275KJ

$Q_{Cooking}$ (Potato) = m×cp×Δt
= 0.5×3.39× (60-25)
= 59.325KJ

Total (Rice + Potato) = 173.79
= 173.79+30% (For Safety)
= 225.79KJ

Mass of PCM -
225×10^{3} = m (2.57) (47-25) +176+4.88(62-25)
m = 544 gram
Rate of heat transfer,

$$\frac{1}{q} = \frac{L_A}{k_A} + \frac{L_B}{k_B} + \frac{L_C}{k_C} + \ldots \quad (2)$$

= 0.003 / 237 + 0.05 / 0.040 + 0.02 / 0.17

μ=0.7311W/m^2 ℃ Area= length × breadth
= 0.6×0.4
= 0.24m^2

Bottom Loss,Q=μ×A×Δt
= 0.7311×0.24× (60-25) = 6.14W

Side Loss,
= 2(0.2×0.4) =0.16m^2
= 2(0.2×0.6) =0.24m^2
= 0.6 + 0.24 = 0.40m^2

Q= μ×A×Δt (3)
= 0.7311×0.40× (60-25)
= 16.08W

I_T = 600W / m^2S = I_T × A_P
S = 600×0.58×0.38 (Reducing 20mm length and breadth frame)
S = 132.24W

q_{useful} = q_{wax} - q_{loss}
= 132.24 – 9.5 – 16.08 – 41.97
q_{useful} = 122.75W

T_{sky} = Ta – 6
= 298 – 6 = 292K

$R_e = \rho VD/\mu$ (4)

Air Temperature, 52.5 + 25 / 2 = 38.75℃

D = 4×0.38×0.58 / 2(0.38+0.58) = 4A / P
= 0.4591R_e = 1.127×2.5×0.4591 /
1.918×10^{-5} = 67440.78
P_r = 0.7 for 38℃

$P_r \times R_e = Ra \cos\beta$ (β = tilt angle) $0.7 \times 67440 = Ra \cos 0$

$Ra = 4.72 \times 10^4$

$Na = 0.229\ (Ra \times L \times \cos\beta)^{0.252}$

$= 0.229\ (4.72 \times 10^4)$

$Na = 3.44$

$Nu = hD / K$ (5)

$3.44 = h \times 0.4591 / 0.02352$

$= 0.176 W/m^2K$

$hw = (T_{c2} - T_a) + \varepsilon\sigma c\ (T_{c2}^{\ 4} - T_{sky}^{\ 4})$

$= 0.176\ (315 - 298) + 5.67 \times 10^{-8} \times 0.89 (42.5^4 - 25^4)$ $Q = 29.92 KJ$

Total Loss = Top Loss + Bottom Loss + Side Loss

= 29.92 + 9.65 +16.08

= 55.65W

$Q_{useful} = 132.24 - 55.65$

$= 76.59W$

Time = $Q_{cooking}$ / Total Loss

$= 225.75 \times 10^3 / 55.65$

Time = 48.96 mins or 2937 sec

Time required for heating of tiffin,

Rth = δ / KA (Aluminum) + δ / KA (Stainless Steel)

$= 1.1 \times 10^{-3} / 237 \times \Pi \times 0.07^2 + 0.05 \times 10^{-3} / 15 \times \Pi \times 0.07^2$

$= 2.27 \times 10^{-4} + 2.65 \times 10^{-3}$

$= 4.905 \times 10^{-4}$

$Q = \Delta T / R_{th} = 55\text{-}30 / 4.90 \times 10^{-4} = 50968.399$

4. Resources and Material Utilized

For the project set up and experimental analysis, the optimum utilization of available resources with minimum involvement of cost is a must. The scrap wooden box is utilized to make solar warmer & its air tight top cover showsthe utilized wooden box, rock wool filled in cavity of box, aluminum foil, black paint, paint brush, transparent glass,glue, knife, scissor, steel rule, plastic sheet and digital temperature sensors. The digital temperature sensors have been utilized to measure the temperature during the exposure of the solar tiffin and to note down the initial temperature & the temperature growth inside the cooker over a periodical interval of time based on the temperature and heat gradient rate authors can conclude on the topic discussed and proposed. Future enhancement can also be briefed here [4].

Table. 1. Physical data of PCM material of Sodium Acetate Trihydrate [5]

Material	m.p.	H_f	Density (kg/dm^3)		Specific heat (kJ/kgK)		Therm. Cond. (W/mK)	
	°C	(kJ/kg)	solid	liquid	solid	liquid	solid	liquid
$MgCl_2 \cdot 6H_2O$	116	165	1.50	–	1.72	2.82	0.69	0.57
$Ba(OH)_2 \cdot 8H_2O$	78	267	2.18	2.06	1.17	–	1.25	0.65
Stearic acid	70	203	0.94	0.95	1.67	2.35	0.3	0.2
$CH_3COONa \cdot 3H_2O$	58	226	1.45	1.28	2.79	–	–	–
Paraffin	55	189	0.9	0.77	1.55	2.1	0.3–0.2	0.16
$Na_2S_2O_3 \cdot 5H_2O$	48	201	1.73	1.67	1.46	2.4–3.05	0.6	–
$Na_2HPO_4 \cdot 12H_2O$	35	281	1.52	1.44	1.9–1.5	1.7–3.2	0.51	0.47
$Na_2SO_4 \cdot 10H_2O$	32	254	1.48	1.41	1.9–1.7	3.31	0.5	0.3
$CaCl_2 \cdot 6H_2O$	29	171	1.62	1.5	1.45	1.47	0.6–1.08	0.3–0.55

5. Fabrication

1 Firstly, we have considered **Wooden Box** of dimension 600*400*200. We have choose wood for outer box because it has the property of heat resistance, cheap, light weight and easily available.
2 Then we have placed **Reflecting Mirror** on the top of the wooden box so that we would get maximum radiations of sun light.
3 Later we filled the wooden box with **Rockwool** (considered 5 kg) has insulation material to minimize the heat loss between inner box and surrounding.
4 Selecting **Sodium Acetate Trihydrate** powder as a phase change material. As it has the capacity to store the heat for longer duration of time.
5 Then we set down upon the **Temperature Sensor** (around 4) for sensing temperature at various places i.e. temperature of Sodium Acetate (Container), Ambient temperature, temperature of Rockwool (Cavity) and temperature of food (Tiffin).
6 Lastly, we have also examined **Pyrometer** interpretation taking into account the global radiation.

Table. 2 - Bill of Materials

Sr. No.	Material	Quantity	Cost (Rs)
1	Rockwool	5 Kg	2000
2	Wooden Box	600*400*200 (mm)	1500
3	Aluminum Foil	1-2	500
4	Glass Cover	1	550
5	Reflecting Mirror	1	540
6	Heating Container	2	1200
7	Sodium Acetate Trihydride	500 gram	350
8	Black Paint	1 Bottle	100
9	Temperature Sensor	4-5	430
Total			**7170/-**

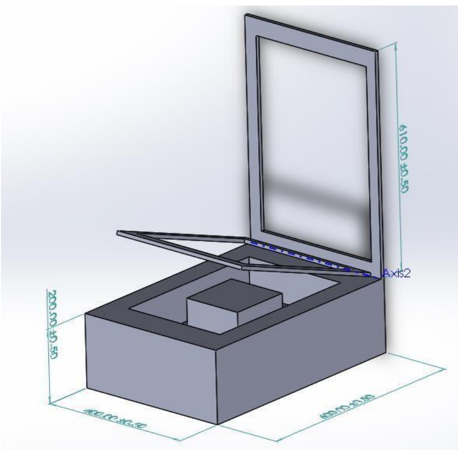


Fig.4. 2D representation of front view of setup

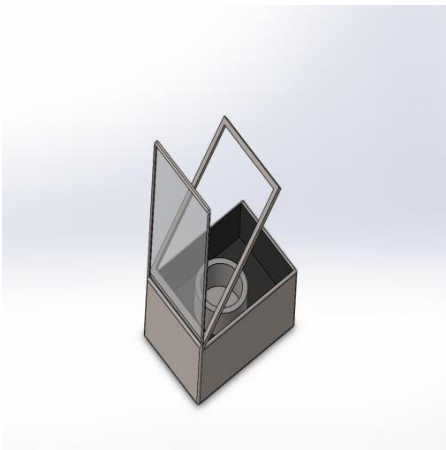


Fig.5. 3D representation of top view of setup


Fig. 6. Actual Model Representation (Top & Front View)

6. Results

Here are the results of experimental analysis with the different food items. We have performed the 1st trial on 19th March as well 2nd and 3rd trials following on 20th & 21st March. We have considered different quantity for trialexperimentation. The initial temperature to the achievement of water temperature of 15°C has been noted down and the time interval also was noted down. The soaking time after getting the desired rise in temperature has also been observed and plotted in graph. The temperature versus time period has been plotted to understand the temperature growth for different food items. In the month of April in Mumbai, i.e. Indian summer season, at 11:30 hrs. The atmospheric temperature noted was 30°C to 39°C when the solar food warmer was kept under atmospheric sunlight area.

Test Trial – 01 (Water Heating Test)

Considering Water = 500ml

Table 3. Readings taken while keeping the set-up outside for solar radiation

Time	Temperature				
(min)	Sodium Acetate (Container)	Ambient (Outside)	Pyrometer (Global)	Rockwool (Cavity)	Box Inner Temp
11:30	28.2	30	902	31	31.7
11:40	40.3	35.2	949	44.4	31.7
11:50	47.4	35.8	999	51.8	31.8
12:00	54.6	36.7	971	53.9	31.8
12:10	57.6	38.3	980	55.4	31.9
12:20	59.1	38.6	963	57.8	33.8
12:30	60	39.8	922	58	35.6
12:40	60.8	38.6	936	58.5	37.2
12:50	60.9	38.8	907	56.8	38.4
1:00	61.7	38.5	883	58.8	39.6
1:10	61.9	38.6	889	59.6	40.5
1:20	62.2	36.9	887	60	41.4
1:30	63.7	39.1	897	56.7	42.1

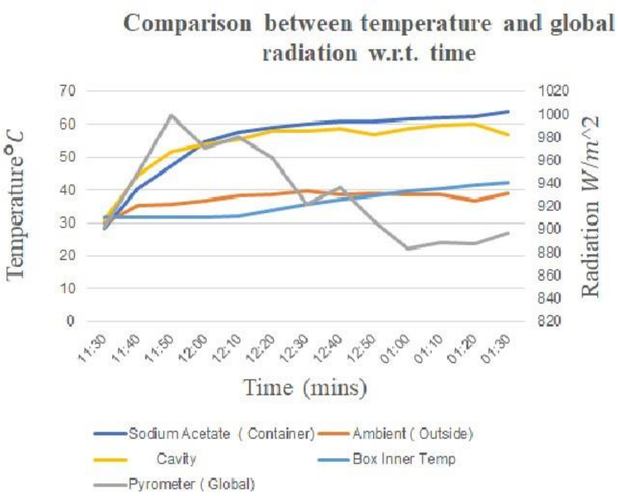
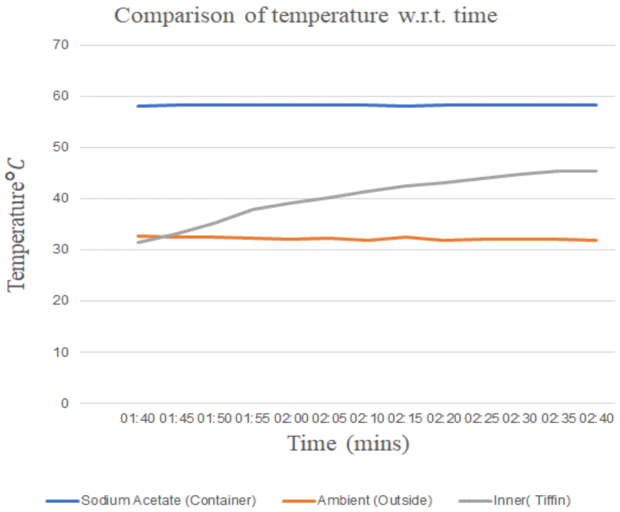


Table 4. Observation taken down while keeping the set up inside the room temperature

Time (min)	Temperature Sodium Acetate (Container)	Ambient (Outside)	Inner(Tiffin)
1:40	58.2	32.6	31.4
1:45	58.3	32.5	33.1
1:50	58.3	32.4	35.3
1:55	58.3	32.3	37.9
2:00	58.3	32.1	39.2
2:05	58.3	32.2	40.3
2:10	58.3	31.9	41.5
2:15	58.2	32.5	42.5
2:20	58.3	31.9	43.2
2:25	58.3	32	43.9
2:30	58.3	32.1	44.7
2:35	58.3	32	45.3
2:40	58.3	31.9	45.5



Test Trial – 02 (Dal Heating Test)

Considering Dal = 250ml

Table 5. Readings taken while keeping the set-up outside for solar radiation

Time (min)	Temperature Sodium Acetate (Container)	Ambient (Outside)	Pyrometer (Global)	Cavity	Box Inner Temp
11:30	39.4	37.2	897	61	29.8
11:40	44.9	40.4	872	63.7	31.6
11:50	49.4	37.9	922	63	32.9
12:00	56.8	39.8	870	62.8	35
12:10	60.1	38.2	912	63.6	36
12:20	61.3	39.5	932	64.5	38.6
12:30	62	38.7	905	65.1	40.3
12:40	62.6	40.9	880	65.3	42.3

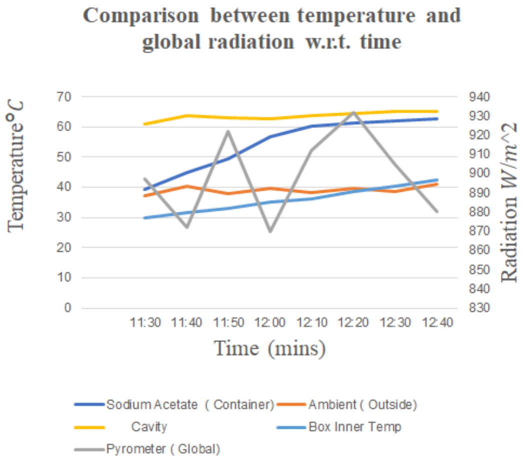


Table 6. Observation taken down while keeping the set up inside the room temperature

Time (min)	Temperature Sodium Acetate (Container)	Ambient (Outside)	Inner(Tiffin)
12:50	58.1	33.2	37
12:55	58.3	32.5	39.5
1:00	58.2	32.6	40.7
1:05	58.2	32.9	41.7
1:10	58.1	32.8	42.8
1:15	58.1	32.6	43.6
1:20	58.1	32.9	44.3
1:25	58	32.7	45.5
1:30	58.2	32.9	45.9
1:35	58.1	32.8	46.5
1:40	57.9	32.9	47.2
1:45	58	32.7	47.5
1:50	57.8	32.9	47.9

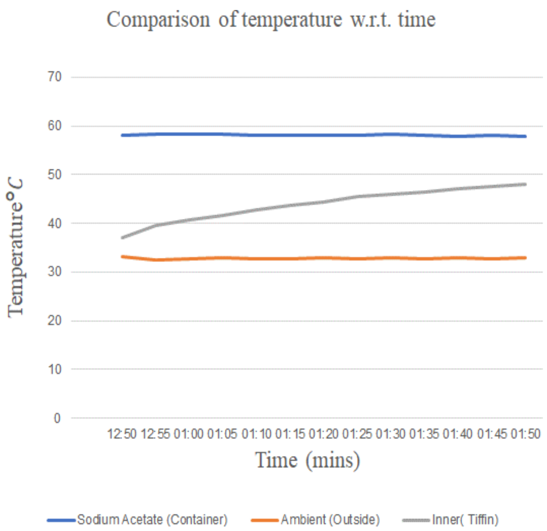


Fig.7. Rise in temperature of water

Fig. 8. Rise in temperature of daal

Interpretation of Result

Thus, considering 1 litre of water and calculating the efficiency of storage we get,

$$
\begin{aligned}
Qstorage &= m\times Cp \times \Delta t + m\times L.H + m\times Cp\times \Delta t \\
&= m\,[2.57\,(58-25) + 180 + 4.88\,(62-58)] \\
&= 1421.65KJ
\end{aligned}
$$

$$
\begin{aligned}
Quse &= m\times Cp\times \Delta t \\
&= 1\times 4.187\times (47-25) \\
&= 92.11\ KJ
\end{aligned}
$$

$\eta storage = Quse / Qstorage = 92.11 /$

$1421.65 = 6.47$Solar Warmer,
Area $= 0.16\times 0.36 = 0.0576\ m^2$

7. Conclusion

Research on phase change systems has focused on several areas throughout the last 30 years, including the basics of design, optimization of systems and processes, transient behaviors, and field performance. The R&D has been extensive and fruitful, with an emphasis on studying the properties of new materials as well as resolving particular phase transition materials and issues. This analysis shows how several researchers have approached the problem of heat transfer solution. Research on the thermophysical characteristics of novel phase change materials has included theoretical, experimental, and computational investigations [8].

Our project has been a significant exploration into harnessing renewable energy for everyday culinary needs. Through meticulous design, rigorous testing, and iterative development, we have successfully created a functional prototype that demonstrates the feasibility and potential of solar-powered tiffin warmers with thermal storage. Our research has shown that integrating solar energy with thermal storage technology offers a sustainable solution for maintaining optimal temperatures in tiffin contents, even in the absence of direct sunlight.

Solar tiffin warmers can lead to several expected outcomes that are beneficial for both individuals and communities. Solar food warmers can reduce the reliance on electricity or gas for food heating, leading to lower energy bills and reduced environmental impact. Over time, it can prove cost effective as they reduce need for fuel consumption. Solar food warmers are designed to be portable, making them suitable for outdoor events, picnic, camping, etc. Continued development in this field can lead advancements in solar technology and materials benefiting other applications beyond solar tiffin box. By reducing the need for indoor open fires or wood burning stoves, solar food tiffin box can improve indoor air quality and reduce health risks associated with smoke inhalation [9].

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