DESIGN AND FABRICATION OF SOLAR IRON BOX USING PHASE CHANGE MATERIAL

A PROJECT REPORT

Submitted by

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BONAFIDE CERTIFICATE

Certified that this project report "DESIGN AND FABRICARION OF SOLAR IRON BOX USING PHASE CHANGE MATERIAL" is the bonafide work of "SANJAY VANYA, ARAVIND, MATHIVANAN, AJITH" who carried out the project work under my guidance.

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INTERNAL EXAMINER **EXTERNAL EXAMINER**

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ABSTRACT

Solar energy can furnish an aplenty origin of renewable energy (i.e. thermal and electrical). However, because of its totter in nature, the solar thermal energy storage system will become pedantic when a powerful portion of total energy will be furnished by a solar source.

Here we have been reporting that concentrating the direct solar energy to the PCM (Phase Change Material) through a parabolic solar concentrator to remove crease in clothes. The latent heat storage capable material is anchored onto a container and possibly charged and discharged with adjusting the accurate focal lengths to achieve better efficiency practically.

The solar iron box reached it experimental peak temperature of 118°C by from 11 minutes of heating with the efficiency of 78.47%. With the measured base temperature of 114°C, the iron box sustained its peak temperature of 19 minutes and able to iron spandex, silk, wool, polyester wrinkle free on multiple passes.

This combined solar-thermal energy-based application grade up better efficiency when weighing up with the conventional electric iron box. It undoubtfully, after 6 years the solar iron box will retrieve the inceptive investment and become profitable for a common man.

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1.INTRODUCTION

Sun is the most primary source of energy in the world, where others are kind of it. The earth is being active because of sun which compensate and gives sophistication. The rate of utilization of energy used from solar mode is depending upon the magnitude of consumption energy. The solar energy is not equally shared in all region of the earth; it is how the heat rays pass through the sun to the land of earth.

Heat is primary source of cooking of variety of food, ironing of clothes etc, and other essential works in world such as

- Agriculture
- Lighting
- Industry
- Water supply
- Other domestic activities

Upon our population in the region like India, the sources of energy are crude oil (i.e. petroleum products), nuclear which are specially take more time to recreate itself. Some of the energies like wind energy, hydel energy, biomass, solar energy are renewable energy where solar is easily available and mostly cost free.

Our project is related to heating of clothes through solar energy, though upon the view of our base research, solar energy can be used in different engineering-oriented practices.

1.1. SOLAR IRRADIANCE

Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation as measured in the wavelength range of the measuring instrument. The solar irradiance is measured in watts per square meter (W/m2) in SI units. Solar irradiance is often integrated over a given time period in order to report the radiant energy emitted into the surrounding environment (joule per square meter (J/m2) during that time period. This integrated solar irradiance is called solar irradiation, solar exposure, solar insolation, or insolation.

1.2. AVAILABLE SOLAR RADIATION AND HOW IT IS MEASURED

Before talking about concentration of light for practical purposes, it would be good for us to review what kinds of natural radiation are available to us and how that radiation is characterized and measured. Solar Irradiance is measured by satellites above Earth's atmosphere,[3] and is then adjusted using the inverse square law to infer the magnitude of solar irradiance at one Astronomical Unit (AU) to evaluate the solar constant.[4] The approximate average value cited,[1] 1.3608 ± 0.0005 kW/m², which is 81.65 kJ/m² per minute, is equivalent to approximately 1.951 calories per minute per square centimeter. **Solar Constant (Extra-terrestrial solar flux intercepted by the Earth) = 1367 W/m2**

1.3. THE SOLAR ENERGY OVERVIEW

- Solar energy is available only during the sunshine hours
- Consumer energy demands follow their own time pattern and the solar energy doesn’t fully match the demand
- Photo-electric effect (i.e. solar panel - pv cells)
- Thermo-chemical storage
- Solar thermal storage.

1.4. THERMAL ENERGY STORAGE METHODS

There are various forms of energy and their storage mechanisms are described below. Such mechanisms include thermal energy storage with phase change materials. The key emphasis is on the latent heat storage method to used store solar thermal energy.

1.5. MECHANICAL ENERGY STORAGE

Mechanical energy storage systems include the energy storage based on gravitation. For example, hydropower storage, storage due to pressure difference, compressed air energy storage and storage due to inertia, and flywheels. Hydropower storage and compressed air energy storage can be used for large scale energy utility while flywheels are more suitable for intermediatestorage. Storage is carried out when off-peak power is available and the storage is discharged when power is needed because of insufficient supply from the base-load plant.

1.6. ELECTRICAL ENERGY STORAGE

Electrical energy is stored through batteries. When the battery is connected to the direct electric current the ionic reactions happen causing the positive and negative ions to separate, resulting in chemical potentials. At the time when the main supply disappears, this chemical energy is converted into electrical energy. The most common types of storage batteries are the lead acid and Ni– Cd. Potential applications of batteries are utilization of off-peak power, load levelling, and storage of electrical energy generated by wind turbine or photovoltaic plants.

1.7. THERMAL ENERGY STORAGE

Thermal energy can be stored as a change in internal energy of a material as sensible heat, latent heat or thermochemical or combination of these. Sensible heat storage is due to temperature change of material while latent heat storage is due to the phase transformation which may be solid-liquid, liquid-gas or solid-solid. Different types of thermal energy storage of solar energy.

1.8. THERMO-CHEMICAL STORAGE

Thermal energy from the sun can be stored as chemical energy in a process called solar thermochemical energy storage (TCES). The thermal energy is usedto drive a reversible endothermic chemical reaction, storing the energy as chemical potential. During periods of high solar insolation, an energy- consuming reaction stores the thermal energy in chemical bonds; when energyis needed, the reverse reaction recombines the chemical reactants and releases energy.

Charging and discharging phenomenon takes place during the breaking and reforming of molecular bonds in a complete reversible chemical reaction. In this case, the stored heat depends upon the amount of storage material, the endothermic heat of reaction, and the extent of conversion.

Incorporating storage into concentrating solar power (CSP) systems enables dispatchable generation, whereby utilities produce power to match demand. This efficient method of power production overcomes intermittency challenges faced by other forms of renewable energy production. It also reduces the cost of solar energy through higher utilization.

Thermochemical storage has inherently higher energy density than latent- or sensible-heat storage schemes because, in addition to sensible heat, energy is stored as chemical potential. The endothermic reactions that could be employed for solar TCES can operate at significantly higher temperatures than current state-of-the-art CSP storage systems (e.g., molten salt storage). Higher- temperature operation enables the use of high-efficiency power cycles. A storage scheme with higher energy density and higher power cycle efficiency could greatly reduce the cost of solar-derived power. The challenge in developing solar TCES, however, is in achieving high enough energy and power density to offset increasingly complex process control, service life, and material compatibility issues inherent in the use of a high-temperature, chemically reactive system.

The thermo-chemical includes sorption and thermo chemical reactions. In thermo chemical energy storage, energy is stored after a dissociation reaction and then recovered in a chemically reverse reaction. Thermo chemical energy storage has a higher storage density than the any other types of storage system, allowing large quantities of energy to be stored using small amounts of storage substances.

Energy storage based on chemical reactions is particularly appropriate for long-term storage applications, e.g., seasonal storage of solar heat, because the process involves almost no energy losses during the storing period. Storage is usually done at ambient temperatures. In this concept, the chemical potential of certain materials is used as the basis for storing and releasing thermal energy with infinitesimal thermal loss. the endothermic reaction of chemical constituents can be triggered through the supply of heat energy for enabling the storage and release processes to occur in chemical materials.

Sorption systems (adsorption and absorption) are based on a chemical process and thus are also considered chemical heat storage. Adsorption occurs when an adsorptive accumulates on the surface of an adsorbent and shapes a molecular or atomic layer. The adsorptive can be a liquid or gas while the adsorbent can be a solid or liquid. Absorption is a process that occurs when a substance is distributed into a liquid or solid and forms a solution.

A thermo chemical includes three main processes are

- Charging
- Storing
- Discharging.

1.8.1 CHARGING

The charging process is endothermic. Thermal energy is absorbed from an energy resource, which could be a renewable energy resource and conventional energy sources like fossil fuels. This energy is used for dissociation of the thermo chemical material, and is equivalent to the heat of reaction or enthalpy of formation. After this process, two materials with different properties are formed that can be stored

1.8.2. STORING

After the charging process components are separately stored with little or no energy losses. The materials are usually stored at ambient temperatures, leading to no thermal losses (except during initial cooling of components after charging). Any other energy losses are due to degradation of the materials.

1.8.3. DISCHARGING

During this process components are combined in a exothermic reaction. The energy released from this reaction permits the stored energy to be recovered. After discharging, new component is generated and can be used again in the cycle.

1.8.4. SOLAR THERMAL STORAGE

Solar thermal storage system includes sensible heat and latent heat. In this method of storage, the direction-oriented practices are much needed and the raysof the sun are perfectly watched to achieve accuracy and better efficiency than other methods of storage.

The selection of an Solar thermal storage is determined by a set of physical, chemical, environmental, and economic properties11:

- Energy density of the storage materia
- Heat transfer and mechanical properties
- Chemical compatibility and stability
- Thermodynamic reversibility
- Environmental impact
- Thermal losses
- Cost.

1.9. PHASE CHANGE MATERIALS

Thermal energy can be stored as a change in internal energy of a material as sensible heat or latent heat, or thermochemical energy storage. Amongst the above-mentioned thermal energy-storage methods, latent heat storage is the most attractive due to high-energy storage at a constant temperature corresponding to the phase transition temperature of the storage material.

In recent years, PCMs have been receiving attention due to their capability of absorbing or releasing large amounts of latent heat when the materials change from solid to liquid or vice versa, with small temperature variations for different applications.

Generally, PCMs can be classified depending on the required temperature range into three categories:

- organic
- inorganic
- eutectics of inorganic and organic compounds.

Organic materials can be further described as paraffin and non-paraffin. Paraffin waxes are saturated hydrocarbon mixtures of numerous alkanes. Paraffin is safe, reliable, predictable, less expensive and non-corrosive. They are chemically inert and stable below 500 °C, self-nucleating, have no segregation, show little volume changes on melting and have low vapor pressure in the melt form.

Non-paraffin including fatty acids and other non-paraffin organic exhibit the features as follows:

a) high heat of fusion,

b) inflammability,

c) low thermal conductivity,

d) low flash points,

e) varying level of toxicity,

f) instability at high temperatures.

Inorganic compounds include salt hydrates, salts, metals, and alloys. These PCMs do not super-cool appreciably and their heats of fusion do not degrade with cycling. Although inorganic PCMs possess large latent heat and highthermal conductivity, there are some problems inherent in inorganic PCMs, such as their tendency to corrode to most metals, tendency of super cooling, incongruent melting, segregation, etc. Organic PCMs suffer from low conductivity, instability and liquid leakage. These PCMs are not ready to be used directly in practical applications due to the undesirable properties. For PCMs to be used as latent heat storage materials, these materials must exhibit certain desirable thermal, physical, kinetic, chemical and economical properties.

1.10. TYPES OF THERMAL STORAGE SYSTEMS ARE

1.10.1. SENSIBLE HEAT

1) Solid (Metal, Stones, Salt)
2) Liquid (Water, Thermal oil, molten salt)
3) Liquid with solid filler material
4) Melting range (Salt)

1.10.2. LATENT HEAT

1) Melting range (Salt)
2) Solid-solid (Salt)
3) Solid-liquid (Water/ice, Salt hydrates paraffin salts).

1.11. SENSIBLE HEAT

Sensible heat storage consists in the increase through heat transfer of the kinetic energy of the molecules of the storage medium, which translates in a temperature increase. Heat that causes a change in temperature in an object is called as sensible heat. Heating a liquid or solid which doesn't change comes under this category. The quantity of heat stored is proportional to the temperature rise of the material.

In sensible TES systems, energy (or heat) is stored/released by heating/cooling a liquid or solid storage material through a heat transfer interaction. The amount of energy input to a thermal energy storage in a sensible heat system is related to the mass of storage material and its heat capacity as well as the temperature difference of the storage medium between its initial and final states. This heat transfer Q can be expressed as:

$$\mathbf{Q = m\ Cp\ (T_2 - T_1)}$$

where m and Cp are denoting the mass and specific heat of the storage material and T1 and T2 is the temperature difference before and after the storage operation. Examples of materials typically used as a storage medium are water, air, oil, rocks, brine, concrete, sand and soil.

1.12. LATENT HEAT

Latent energy storage makes use of the enthalpy difference of a given substance between two physical states or phases. All pure substances in a nature are able to change their state (Phase Change Materials). Solids can became liquids (ice to water) and liquids can become gases (water to vapor) but changes such as these require the addition or removal of heat.

Latent heat involves the change of a substance from one phase to another at a fixed temperature. In latent thermal energy storage systems, energy is stored during the phase change (e.g. melting, evaporating and crystallization). Due to the specific heat of a typical medium and the high enthalpy change during phase change, the latent heat change is usually greater than the sensible heat change for a given system size. Latent heat storage materials are usually useful over a small temperature range [5]. The stored energy during a latent storage process can be evaluated as:

$$\mathbf{Q = mL}$$

where m denotes the mass and L is the specific latent heat of the phase change material (PCM). Examples of PCMs are water/ice, paraffin and eutectic salts. An example of an industrial PCM is the hand warmer (sodium acetate trihydrate). PCMs are usually packed in tubes, plastic capsules, wall board and ceilings and they are supplied mainly in three shapes: powder, granulate and board.

Above mentioned thermal energy storage technique, which is known as the latent heat storage technique is one of the best energy storage techniques because of its high energy storage density and its characteristics to store heat at constant temperature called phase transition temperature of PCM. Phase change can be in the following form: solid-solid, solid-liquid, solid-gas, and liquid-gas and vice versa

It has been categorized that latent heat storage as our main mode of storage system, itacts as an adaptive and absolute option to store thermal energy, we had investigated wide range of phase change materials such as salt hydrates, paraffin waxes, non-paraffin organic compounds.

The feasibility of PCM is depending upon the life of the storage material (i.e. PCM shouldn't tend to go more changes in melting and thermal cycles). As the selection of storage system in thermal zones, the way of application that we going to fabricate identify either sensible or latent type of thermal storage system

As we optioned latent heat storage as our main criteria because,

- The latent heat storage stores higher heat when compared with sensible heat storage
- Fast charging and discharging ability

As our design needs higher heat, we finalized the latent heat storage.

There are many types of phase change materials namely,

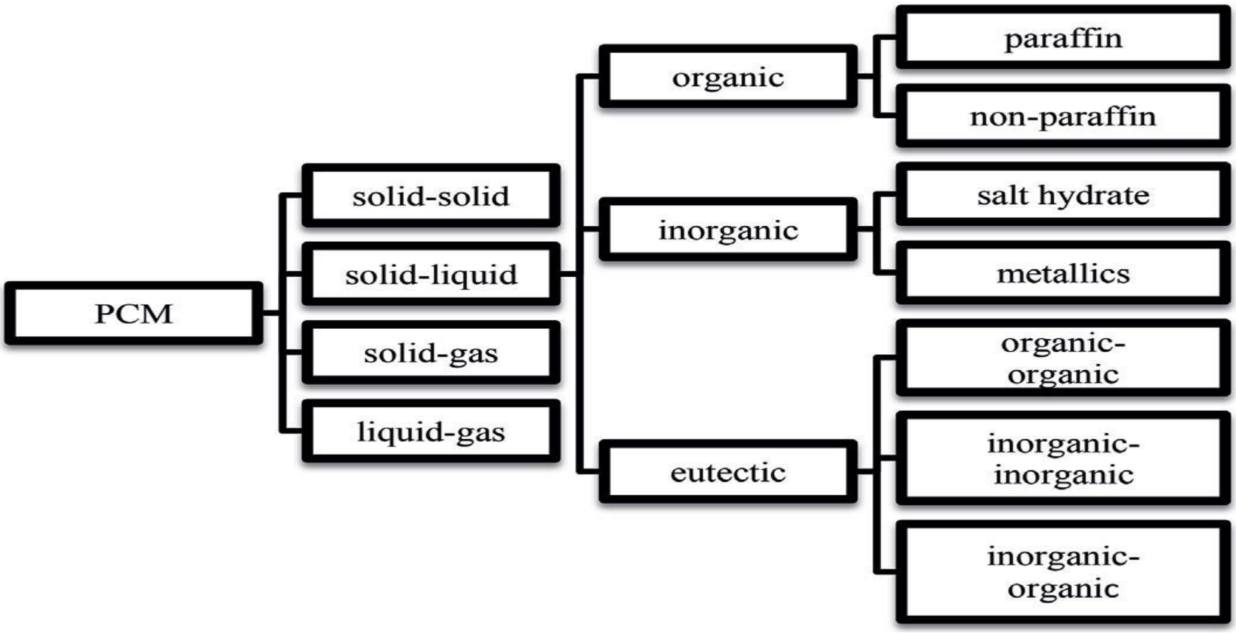

Fig 1.9 Classification of PCM

1.12.1. SOLID -SOLID TRANSITION

- Change in crystalline structure
- Small change in volume
- Smaller storage capacity than solid liquid transition
- Less containment required and greater design flexibility

1.12.2. SOLID–GAS OR LIQUID GAS TRANSITION

- Higher latent heat of phase transition
- Larger volume changes on phase transition
- Larger containment required
- Impractical and complex system

1.12.3. SOLID-LIQUID TRANSITION

- Intermediate latent heat of phase transition, volume change
- Most practical and economical system

In solid system, heat is stored in a material when it melts, and heat is extracted from the material when it freezes, heat can also be stored when a liquid changes to gaseous state, but as the volume change is large, such a system is noteconomic

Latent heat arises from the work required to overcome the forces that hold together atoms or molecules in a material. The regular structure of a crystalline solid is maintained by forces of attraction among its individual atoms, which oscillate slightly about their average positions in the crystal lattice.

We were decided to move our project in the view of latent heat derived storage under the topic of solar thermal storage, in this type we initiate our design and fabrication through the mode that follows below,

Table 1.1 PCM Classification

Description	Term of phase change	Heat movement
Solid –liquid	Melting	Heat goes into the solid as it melts
Liquid-solid	Freezing	Heat leaves the liquid as it freezes

To achieve more heat from a material, it should have more latent heat and medium melting zones, to substitute the needed objectives erythritol has good properties listed below (ref),.

1.13. PARABOLIC CONCENTRATORS

The parabolic trough reflector is a solar thermal energy collector designed to capture the sun’s direct solar radiation over a large surface area and focus, or more generally “concentrate it” onto a small focal point area increasing the solar energy received by more than a factor of two which means more overall heat per square meter of trough.

The shape of concentrating solar collectors must be specifically designed so that all the incoming sunlight reflects off the surface of the collector and arrives at the same focal point no matter what part of the collector the sunlight hits first.

Concentrating solar collectors for residential applications are usually a "U-shaped" parabolic trough (hence their name) that concentrates the sun's energy on an absorber heat tube called a receiver that is positioned along the focal point axis of the reflective trough.

Parabolic Trough Reflectors or PTR, are made by simply bending a sheet of reflective or highly polished material into a parabolic shape called a parabola. Since solar light waves essentially travel parallel to each other, this type of solar collector can be pointed directly into the sun and still achieve a total focal output from all parts of the trough shaped reflector as shown.

1.14. PARABOLIC SOLAR COLLECTORS:

Parabolic solar collectors are classified as Parabolic Dish type or Parabolic Trough type collectors. Classification is based on the geometry of the receiver i.e. dish or trough. The parabolic trough collectors are further classified as tracking and non- tracking type collectors depending on the applications and the desired outlet temperature parameters of the output fluid. The non-tracking types are fixed type collectors. The tracking collectors are again classified into single-axis tracking and two-axis tracking.

1.15. BASIC FEATURES OF PARABOLIC SOLAR COLLECTORS:

The parabolic solar collector consists of the main three components, the parabolic solar reflector, a mounting stand and the receiver engine or the absorber pipe. The parabolic reflector could be a dish type construction or a trough type construction. In case of a parabolic dish the entire incident solar radiation is concentrated at a focal point and it is collected by a receiver device called the engine. This highly concentrated energy is converted into thermal energy by this engine for further storage in thermal devices .In the case of a parabolic trough, the insolation is reflected from the reflector surface and concentrated in a linear axis of the parabolic receiver. The heat absorbing tube containing the working fluid is mounted in this axis and picks upthe heat from the heated tube and thus converts into thermal energy of the working fluid. The same is either stored in thermal storage tanks or used to heat other fluid in heat exchangers.

1.16. PARABOLIC TROUGH SOLAR COLLECTORS:

The two types of parabolic collectors are Simple Parabolic collector and compound parabolic collector. The simple parabolic collector consists of a single parabolic reflective surface. The compound parabolic concentrator consists of two parabolic reflective surfaces and the superimposed focal axis ofboth the parabolic surfaces receives radiation of much higher intensity when compared with a simple parabolic collector

The parabolic trough reflector when used as a solar thermal energy collector is constructed as a long parabolic reflecting mirror which is usually painted a reflective silver, or made from polished aluminium, or uses mirrors whichextends linearly into the trough shape. A metal black heat tube inside a sealed glass tube which can also be evacuated is used to reduce heat losses. The heat tube contains a heat-transfer fluid which is pumped around a loop within the tube absorbing the heat as it passes through.

The most important properties for an efficient concentrator are a highly specular reflectance for light of all wavelengths in the solar spectrum as well as a precise parabolic shape. Specular reflectance means that as many rays as possible are reflected according to the “angle of incidence equals the angle of reflection” law and as few rays as possible are absorbed or scattered. Deviations in the parabolic shape cause the radiation to “miss” the absorber tube.

The parabolic trough reflector can generate much high temperatures more efficiently than a single flat plate collector, since the absorber surface area is much smaller. The heat transfer fluid which is usually a mixture of water and other additive’s or thermal oil, is pumped through the tube and absorbs the solar heat reaching temperatures of over 200oC.

1.17. PARABOLIC-DISH SOLAR CONCENTRATOR

Parabolic-dish solar concentrators are two-axis solar tracking systems that concentrate the solar radiations toward the thermal receiver located on the focal point of the dish collector as demonstrated below figure. The focused rays are concentrated at a small area. The receiver shown in Figure is usually made of a sheet of high thermal conductivity metal, (copper or aluminum). A highly absorbent material is coated to improve the absorptivity and reduce the reflectivity.

1.18. TYPES AND ELEMENTS OF CONCENTRATING COLLECTORS

Any general setup for the conversion of the solar energy includes a receiver - a device that is able to convert the solar radiation into a different kind of energy. This can be either a heat absorber (to harvest thermal energy) or a photovoltaic cell (to convert light to electric energy). In the first case, the thermal radiation is absorbed to heat a medium (fluid), which transfers that absorbed energy to a generator. In the second case, light causes photovoltaic effect in the material of the solar cell, which generates electric current. In both of these situations, the amount of energy available for the conversion is only as much as the solar source supplies per unit area of the converter.

If we need more energy for use, we have two options. The first option is to increase the system scale (for example by increasing the number of receivers). In other words, we have to expand the plant area, which would involve additional cost for construction, service, maintenance, and may require additional land, more materials, etc. It has been done to some extent, but sometimes it is not a sufficient measure to meet the energy demands, especially if land area is a constraint. The second option is to concentrate the radiationflux. This can be achieved by placing a concentrator (usually some kind of optical device) between the light source (sun) and the receiver. By common terminology, a solar collector is a sunlight processing system that includes a concentrator and a receiver in its setup; it is also characterized by aperture - the cross-sectional area through which sunlight accesses the system.

The most common concentrators are reflectors (mirrors) and refractors (lenses), which modify and redirect the incident sunlight beam. The design of the concentrating optics varies. Some of the examples of concentrating collectors, which involve diversely shaped mirrors, are shown in Figure 2.3, as they applied to the solar-to-thermal energy conversion.

The process of light concentration implies first of all that the energy flux is increased due to confining it to a smaller area. This brings several important benefits:

- Reaching higher temperatures for heat collectors;
- Heat losses from the surface of the receiver are decreased because the receiving area is decreased;
- Higher energy conversion rate can be achieved over smaller area.

There are two major classes of solar concentrators:

- Imaging
- Non-imaging.

Imaging concentrators are called imaging because they produce an opticalimage of the sun on the receiver. Non-imaging concentrators do not produce such an image, but rather disperse the light from the sun over the whole area of the receiver. Non-imaging concentrators have relatively low concentration ratio (<10) compared to the imaging concentrators.

LITERATURE SURVEY

Table 2.1 Literature survey

SI NO	AUTHOR	JOURNAL & YEAR	INFERENCE
1	Saša Pavlović , Velimir Stefanović , Darko Vasiljević and Emina Petrović	Optical Design of a Solar Parabolic Concentrating Collector Based on Trapezoidal Reflective Petals. (2015) 714-720	The design of parabolic reflectors with Trapezoidal Reflective Petals has been analyzed.
2	T. Rama Raoand Piyush Ranjan Ojha	Performance Analysis of Paraboloid Solar Collector. [April 2018] 2319-6491	Explains collecting low density solar energy and converts it into high density energy by Paraboloid solar collector which can be further developed efficiently for commercial utilization.
3	K.Kavitha and S.Arumugam	Performance of paraffin as pcm solar thermal energy storage. International Journal of Renewable Energy Resources 3 (2013) 1- 5	The possible use of paraffin as as thermal energy storage material and study the melting and solidification characteristics of paraffin as a phase has been analyzed

			change material.
4	R.T. Ramteke, C.N. Gangde, S.R. Kalbande	Review on Phase Change Materials in Different Solar Gadgets. (2016)2231-5381	PCMs used in different solar systems. Its review of solar air heating systems with storage units include space heating systems, greenhouses with various thermal storage materials, solar air heaters integrated with various storage materials and heat transfer studies on air as a heat transfer fluid.
5	P. V. Honguntikar and U. C. Pawar	Characterization of Erythritol as a Phase Change Material. (2019) 2395-1052	The use of erythritol as PCM and its properties during multiple heating and cooling cycle has been studied and analyzed.
6	Nan Sheng, Kaixin Dong, Chunyu Zhu, Tomohiro Akiyama, and Takahiro Nomur.	Thermal conductivity enhancement of erythritol phase change material with percolated aluminium filler Materials Chemistry and Physics Volume 229, 1 May 2019, Pages 87-91	The use composite PCM made of erythritol and aluminium and describes a high thermal conductive phase change composite (PCC) of erythritol and Al filler with percolating network has been analysed.

2.1 OBJECTIVES:

Based on the literature survey the following objectives are formulated.

1. To efficiently use solar parabolic concentrator to harvest the solar radiation and transfer the radiation to the iron box as thermal energy
2. To ensure the Phase change material is at optimum temperature to ironthe clothes.
3. To analyses the efficiency of the parabolic reflector.
4. To design the solar iron box with flat base with high thermal conductivity and minimum convective heat transfer loss.
5. To ensure the container is free from any leakages.
6. To ensure the sealants are capable of withstanding the high temperature.
7. To iron at least 3 material types wrinkle free.

3.DESIGN

Table 3.1 DESIGN PARAMETERS AND ITS SYMBOLS

PARAMETERS	UNITS	SYMBOLS
APERTURE WIDTH	M	W
APERTURE DEPTH	M	D
FOCUL POINT	M	f
RIM ANGLE	Ra d	R_{ang}
ANGULAR WIDTH	Ra d	W_{ang}
APPERTURE AREA	m^2	A_{ap}
SOLAR RADIATION	W/m^2	G
EFFICIENCY	%	η
MASS OF PCM	Kg	M
SPECIFIC HEAT SOLID	kJ/kgK	C_{ps}
SPECIFIC HEAT LIQUID	kJ/kgK	C_{pl}
DENSITY	kg/m^3	ρ
TERMAL CONDUCTIVITY SOLID	W/mK	k_s
THERMAL CCONDUCTIVITY LIQUID	W/mK	k_l
ROOM TEMPERATURE	^oC	T_r
MELTING POINT	^oC	T_m
BOILING POINT	^oC	T_b
LATENT HEAT	kJ	Q_L
DIFFUSED SOLAR RADIATION	W/m^2	G_d
TOAL SOLAR RADIATION	W/m^2	G_t
HEIGHT OF THE PCM CONTAINER	M	H
DIAMETER OF THE PCM CONTANIER	M	H
VOLUME OF THE PCM CONTAINER	m^3	V_c

3.1. DESIGN OF PARABOLIC REFLECTOR

Solar Flux	=	1 kWh/hr (Theoretical available solar flux)
Aperture Width	=	1.5m
Aperture Depth	=	0.3m
Rim Angle (R_{ang})	=	77.31°

3.2. FOCAL POINT OF THE PARABOLIC REFLECTOR

The focal point is the point in space at which light incident towards the mirror and traveling parallel to the principal axis will meet after reflection. All incoming rays parallel to the axis of the parabola are reflected through the focus. This provides an opportunity for light concentration by using parabolicsurfaces.

Focal Point (f) = $(W/2)^2 / (4D)$

= $(1.5/2)^2 / (4*0.3)$

= 0.46875m

3.3. APERTURE AREA OF THE PARABOLIC REFLECTOR

Aperture area is the area in a collector through which unconcentrated solar radiant energy is admitted to the collector. It's the area of the collector where the solar radiations are reflected to the focal point. The effective aperture area isthe area of the collector that's much effective in concentrating the solar radiations reflected from its surface. As the effective aperture area is proportional to the amount of solar radiations concentrated on the focal point, we can conclude that larger the aperture area higher the concentrated intensity of radiation at the focal point.

Aperture Area (A_{ap}) = $(\pi * D^2)/4$

= $(\pi*1.5^2)/4$

= $1.76625m^2$

3.4. TOTAL FLUX RECEIVED BY THE COLLECTOR

Total Flux = A_{ap}*G

= 1.76625*1.0

= 1.76625 W/m^2

3.5. IMAGE DIAMETER

Parabolic trough is a typical example of an imaging concentrator. A parabolic mirror produces an image of the sun on the surface of the receiver, so the receiver size needs to be matched to the image size. Figure below illustrates thisidea. Since the sun is not really a point source, solar beam incident on the reflector is represented as a cone with an angular width 0.53o (so the half-angle between the cone axis and its side is 0.267o). Being reflected at a point on the parabolic surface, the beam hits the focal plane, where it produces an image of acertain dimension, centered around the focal point. The diameter of the cylindrical receiver, which would intercept the entire reflected image can be theoretically calculated using aperture width, and rim angle.

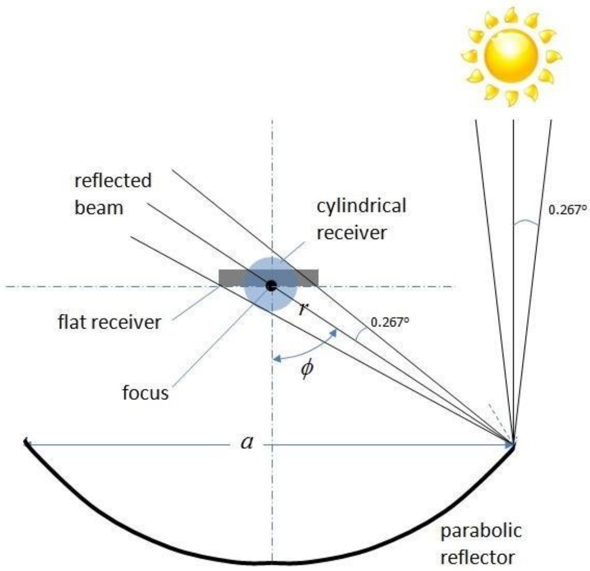

Figure3.1 Solar image Formation

Image Diameter = W*sin (0.267) / sin (R_{ang})

= 1.5*sin (0.267) / sin (77.31°)

= 0.03361m

3.6. ENERGY STORAGE CAPACITY OF PHASE CHANGE MATERIAL

Table 3.2 Properties of Erythritol

PCM PROPERTIES		
Parameter	**Data**	**Units**
Material	Erythritol	
Mass	1	Kg
Specific Heat, solid	1.38	kJ/kgK
Specific Heat, liquid	2.76	kJ/kgK
Density of PCM, Solid	1480	kg/m^3
Density of PCM, Liquid	1300	kg/m^3
Melting Temperature	390	K
Latent Heat	169	kJ/kg
Thermal Conductivity, Solid	0.733	W/mK
Thermal Conductivity, Liquid	0.326	W/mK
Boiling Point	390	K
Room Temperature	303	K
Peak Temperature	393	K
Heat of Fusion	340	Kj/kg

The storage capacity of a phase change material heated from T_1 to T_2, if it undergoes a phase transition at Tm, is the sum of the sensible heat change of the solid (the lower temperature phase) from T_1 to T_m, the latent heat at T_m, and the sensible heat of the liquid (the melt, or higher temperature phase) from T_m to T_2.

ENERGY DENSITY/THERMAL STOREAGE OF ERYTHRITOL:

Qs = m [Cs (Tm – T1) + λ + C_l (T2 – Tm)]

= 1*[1.38*(390-303) + 340 + 2.76(393- 390)]

= 468.68 kJ/kg.

Charging cycle consist sensible heat phase, latent heat phase and high temperature latent heat phase. During the sensible charging phase, the temperature raises with constant enthalpy. During the latent heat charging phase, the temperate of the material remains constant but the enthalpy continuous to increase. After the latent heat charging phase, the temperature continues to climb as long as the supply continues. The temperature range of the sensibleheat phase is 35-113 degree Celsius.

3.7. DESIGN OF SOLAR IRON BOX

The dimensions are essential to design the container. The dimensions are calculated based on the volume of the PCM. From the PCM calculation the we concluded to use 1kg of phase change material. On further study the optimum thickness of the insulation is made to be 2cm made of glasswool.

Volume of the Phase change material = Mass * Density

= 1*1480

= 1480dm^3

= 1.48L

From the volume we calculate the dimension of the containers. The volume of the containers usedare little larger the need to provide expansion allowances for the PCM inside the container.

Container	Diameter(cm)	Height(cm)	Volume
PCM Container	15	9	1589.625
Insulation Container	17	11	2495.515

3.8. MODELLING

A model of iron box and its features is made using various options of Solidworks, initially Base plate of diameter 170mm and thickness of 0.45mm isdesigned, the material used here is copper (Cu) and with a gauge of 26, which carries high thermal conductivity of 385 W/m K.

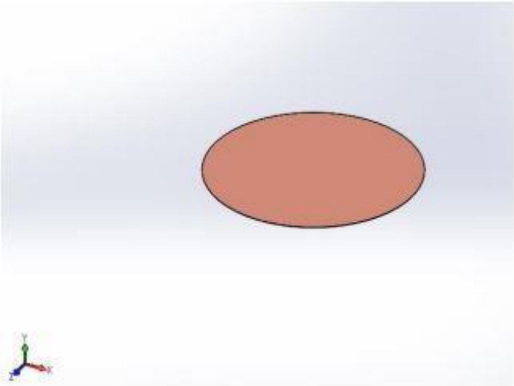

Figure 3.2 Copper base plate

side wall of the container is designed with the dimension of outer diameterof 170mm and material used here is stainless steel.

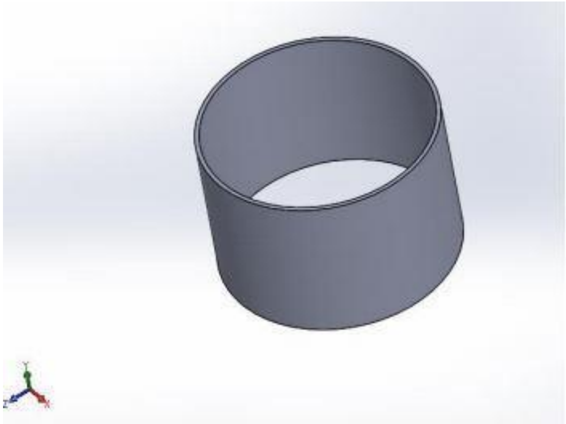

Figure 3.3 Insulation Container

The Phase change material container is designed to carry the PCM at higher temperature with the dimensions of outer diameter of 150mm.

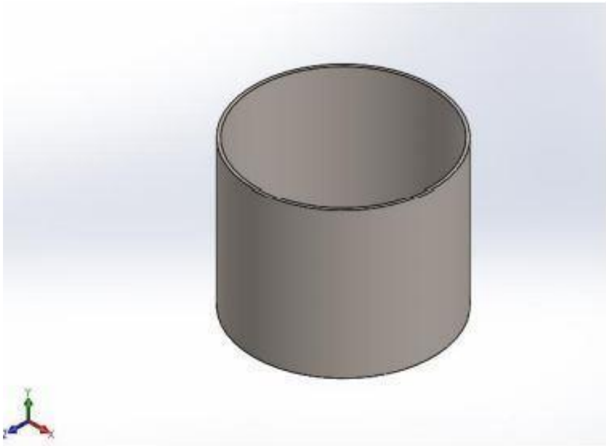

Figure 3.4. PCM Container

To provide an initial insulation or arresting of latent heat of PCM, a top closure is designed for both PCM container and outer container. PCM container closure is designed with the dimensions of outer diameter of 152mm which provide perfect fixed closure to PCM container, and material used here is stainless steel.

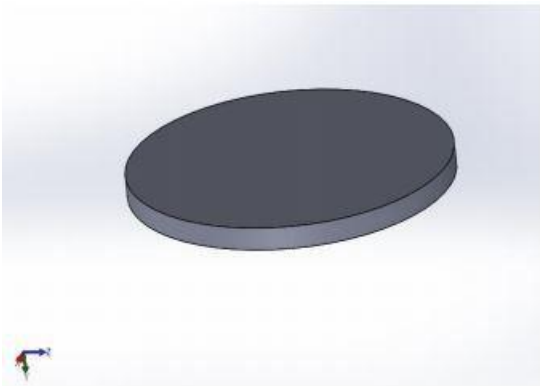

Figure 3.5 PCM Container cover

Outer container closure is designed with dimensions of outer diameter of 172mm and material used here is stainless steel.

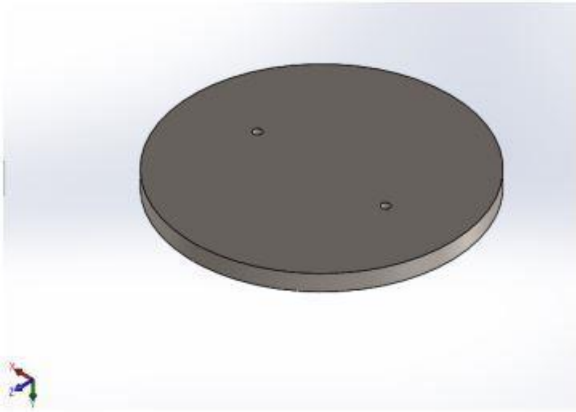

Figure 3.6. Insulation Container cover

To hold the total part, the top handle is designed with hold able 38 dimensions, and material used here is stainless steel.

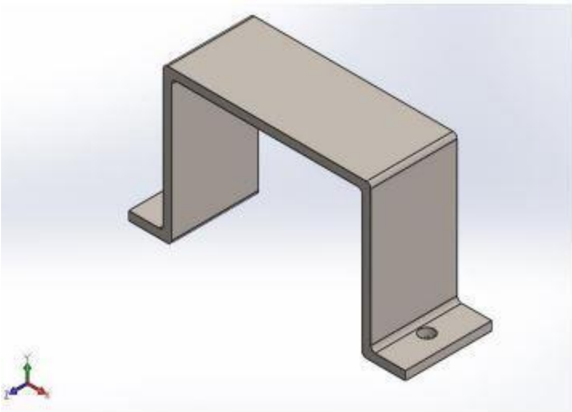

Figure 3.7 Handle

3.9. EXPLODED VIEW

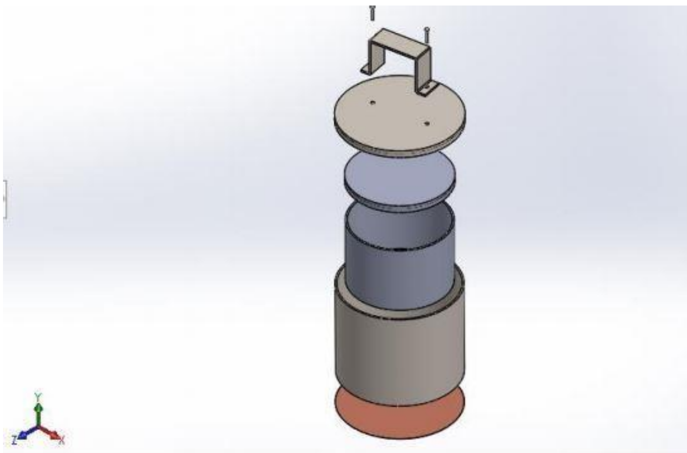

Figure 3.9. Exploded view

4. FABRICATION

4.1. DRAWING

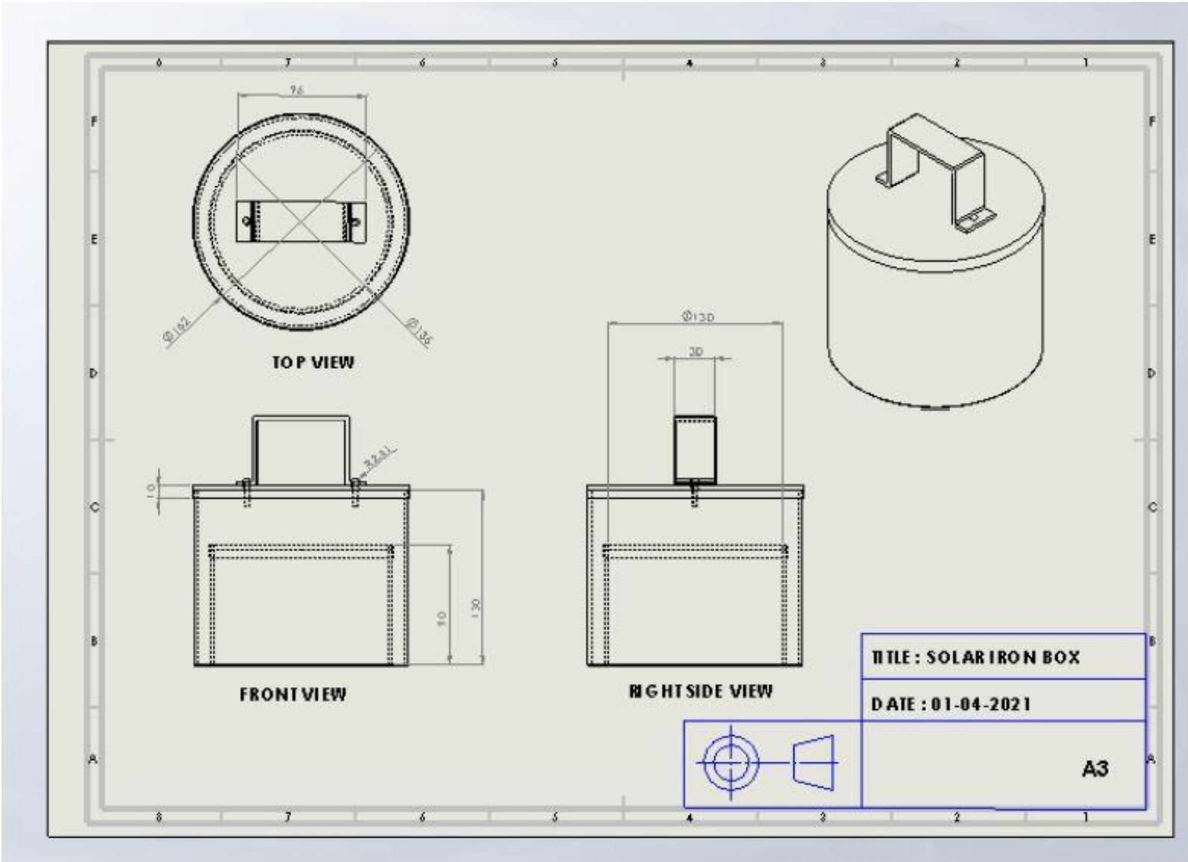

Figure 4.1 Manufacturing Drawing

4.2. BILL OF MATERIALS

Table 4.1 Bill of material

ITEM NO.	PART NUMBER	MATERIAL	QTY.
1	Bottom plate	Copper	1
2	PCM container closure	Stainless Steel	1
3	PCM filled container	Stainless Steel	1
4	Top closure	Stainless Steel	1
5	Top handle	Stainless Steel	1
6	Rivets	Stainless Steel	2
7	Side wall of container	Stainless Steel	1

4.3. MATERIAL USED

TABLE 4.2 MATERIAL

Material Purchased			
S. No	**Material**	**Dimensions (mm)**	**Quantity**
1	Copper	200 X 200 X 0.45	1
2	Insulation Container (Cylinder)	170 X 100	1
3	PCM Container (Cylinder)	130 X 80	1

4.4. FABRICATION PROCESS

Cutting has been at the core of **manufacturing** throughout history. For metals many methods are used and can be grouped by the physical phenomenon used. It is the **process** of producing a work piece by removing unwanted material from a block of metal.

Figure 4.2 Cutting wheel

4.5. PROCEDURE FOR FABRICATION

The outer part of the container and the inner part of the container were purchased with the size which the inner part is suitably seated inside the outer container with the provision of the insulation.

Initially the outer part of the base is marked on the part to be trim and it was machined to make a circular hole using the cutting machine, now the base portion of the outer container is eliminated.

Figure 4.3 Insulation Container

Figure 4.4 PCM Container

Then, the inner container's base part was also removed in order to seat on the base of the iron box. By the approach of cutting machine at the eliminated portion, there will be minute burrs available in that portion. To remove that burrs, Abrasive mounted stone rotary grinding wheels bit with shank diameter of 6mm was fixed to the drilling machine and finely approached throughout from axis of the container.

Figure 4.5 Drilling Machine Figure 4.6 Cylindrical Grinding wheel

After the elimination of base part of the inner and outer container, the base plate is adjusted with the dimensions of the outer container's circumference. Here, we used copper sheet metal as a base plate, the straight snips are used to remove the sheet metal over the diameter of 160mm.

Figure 4.7 Copper Base plate

After that, using the abrasive mounted stone rotary grinding wheel bit, the burrs were removed on the circumference of the base plate Now, both the container were able to seated on the base plate Due to the high temperature approached zone, the base plate is to be fixed rigidly to the container, so the containers and base plate are joined using Brazing After the joining process, the core portion of the iron box got ready to provide a good insulation at the gap between inner container and outer container, we have compressed and fix the glass wool inside it.

Figure 4.8 Containers with base plate assembled

5.EXPERIMENTAL RESULTS AND DISCUSSION

The fabricated containers are tested under the working conditions to ensure the structural rigidity of the assembly under high temperature. To ensure the PCM is melted completely the insulation has been provided to prevent the convective heat transfer loss

5.1 TESING LOCATION

Location : Coimbatore
Latitude : 11.267
Longitude : 76.98
Sea Level : 411 m

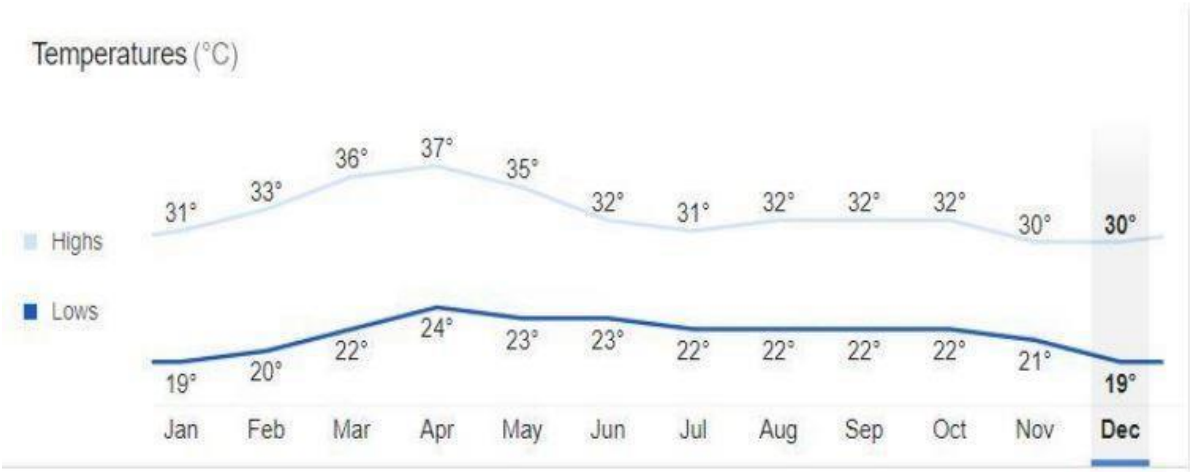

Figure 5.1 Temperature at Coimbatore throughout the year

5.2 PYRANOMETER

Pyranometer is used to measure total hemispherical radiation - beam plus diffuse - on a horizontal surface. If shaded, a pyranometer measures diffuse radiation. Most of solar resource data come from pyranometers. Pyranometers are irradiance sensors that are based on the Seebeck- or thermoelectric effect. The main components of a pyranometer are one or two domes, a black absorber,a thermopile, the pyranometer body and in some cases additional electronics.

Figure 5.2 Pyranometer

5.3 TESTING PROCEDURE

- The Container is checked for any leakages.
- The PCM container is filled with PCM closed Tightly
- The space between the outer container and the insulation container is filled with insulation material Glass Wool. The Insulation container is sealed tightly. The Container is placed in the fixture of the parabolic reflector.
- The container left to charge on the holder
- The pyranometer is placed near the parabolic reflector to measurer the radiation.
- The pyranometer to measure the diffused radiation is placed a shadowneat the parabolic reflector.
- A thermocouple is placed inside the PCM container to monitor the temperature.
- After the container is partially opened to ensure the PCM is melted completely.

- Then the container is left on the fixture for few minutes to increase the temperature.
- The Container is removed form it fixtures and the thermocouple is removed.

Figure 5.3 Parabolic Reflector

Figure 5.4 Experimentalsetup

Figure 5.5 Experimental Setup

5.4 PYRANOMETER READINGS

Table 5.1 Pyranometer readings

Time (hr:min)	Diffused radiation (W/m^2)	Total radiation (W/m^2)	PCM temperature (C)
13:02	138	888	34
13:02	139	887	35
13:02	142	888	36
13:02	145	887	38
13:03	148	885	40
13:03	150	885	45
13:03	164	883	53
13:03	192	883	53
13:03	136	884	60
13:03	133	882	64
13:04	133	880	66
13:04	132	872	69
13:04	132	871	71
13:04	133	872	73
13:04	128	872	77
13:04	129	873	77
13:05	132	872	79
13:05	132	866	81
13:05	132	869	83
13:05	132	868	85
13:05	132	866	87
13:05	132	863	89

13:06	132	860	90
13:06	132	861	92
13:06	132	870	99
13:06	131	875	102
13:06	127	876	107
13:06	121	874	113
13:07	121	875	114
13:07	129	875	115
13:07	132	873	116
13:07	132	874	116
13:07	133	878	116
13:07	133	882	116
13:08	133	884	116
13:08	134	887	116
13:08	134	892	112
13:08	131	894	114
13:08	129	894	115
13:08	132	897	117
13:09	131	897	117
13:09	127	894	116
13:09	136	865	117
13:09	139	879	118
13:09	140	886	115
13:09	138	887	115
13:10	131	892	116
13:10	129	895	116
13:10	129	898	116

5.6. ANALYSIS OF DATA FROM THE PYRANOMETER

The Above table shows the amount of diffused radiation, direct radiation and the temperature of the PCM in the container. It Took the PCM a Total time of 19 minutes to melt. It the insulation were sufficient to prevent the convective heat transfer loss. The copper base greatly influenced the melting time of the PCM

Table 5.2 Calculation

Time (s)	Initial Temperature (C)	Final Temperature	Δ T	Average Diffuse (W/m^2)	Average Total (W/m^2)	Average Direct (W/m^2)
480	30	118	88	135.375	880.857	745.482

5.7. EFFICIENCY CALCULATION

`

Solar Flux per Square meter = 880 W/m^2

Aperture Area of the Parabolic reflector = 1.766 m^2

Total Solar Flux incident on the Reflector (G_R)

= 880 X 1.766

= 1554.08 W

Parabolic Aperture efficiency(η_R) = 0.8

Reflective Index (μ) = 0.8

Parabolic Reflector Efficiency = G_R X η_R X μ

= 1554.08 X 0.8 X 0.8

Total Heat Input to the solar Iron box = 994.6112 W

1W = 1 j/s

Duration the Energy is supplied=10mins

= 600s

Total Heat Input to the solar Iron box = 994.61 X 600

Total Heat Input to the solar Iron box = 596.76 6 Kj

Energy absorbed by the PCM(Qs) = $m [C_s (T_m – T_1) + \lambda + C_l (T_2 – T_m)]$

= 1*[1.38*390-303) + 340 + 2.76(393- 390)]

` **Energy absorbed by the PCM(Qs) = 468.34 Kj**

Efficiency = Energy absorbed by the PCM / Heat Input

= 468.34/ 596.766

Efficiency = 78.47%

5.8. COST OF MATERIAL USED

Table 5.3 Cost of material used

S. No	Product	Quantity	Cost per unit (₹)	Total (₹)
1	Parabolic Dish	1	3000	3000
2	Erythritol	1 Kg	800/Kg	800
3	Copper plate	2 Kg	400/Kg	800
4	PCM Container	1	180	180
5	Insulation Container	1	340	340
6	Cutting Wheel	2	40	80
7	Cylindrical Grinding Wheel	2	20	40
8	Glass wool	1	200	200
Total				₹ 5440

5.9 BREAK EVEN ANALYSIS

The monthly expense of owing an electric iron box is give in the table below.

Table 5.4 calculation for Electric Iron box operating cost

Electric Iron Box Expense	
Capital	₹ 2,000
Energy consumption (W)	1800
Hours used per day	0.3
Energy consumer per day (W)	540
Cost per unit	₹ 5.00
Cost per month	₹ 81.00

In solar iron box, the PCM life is a total of 800 charging and discharging cycles. After 2 Years the PCM have to be replaced. The cost of PCM replacement is divided and placed as monthly expense.

Table 5.5. calculation for solar Iron box operating cost

Solar iron box Expense	
Capital	₹ 5,440.00
Energy Consumption (W)	-
Hours used per day	0.3
Energy Consumer per day (W)	-
Cost per unit	-
Cost per month	₹40.00

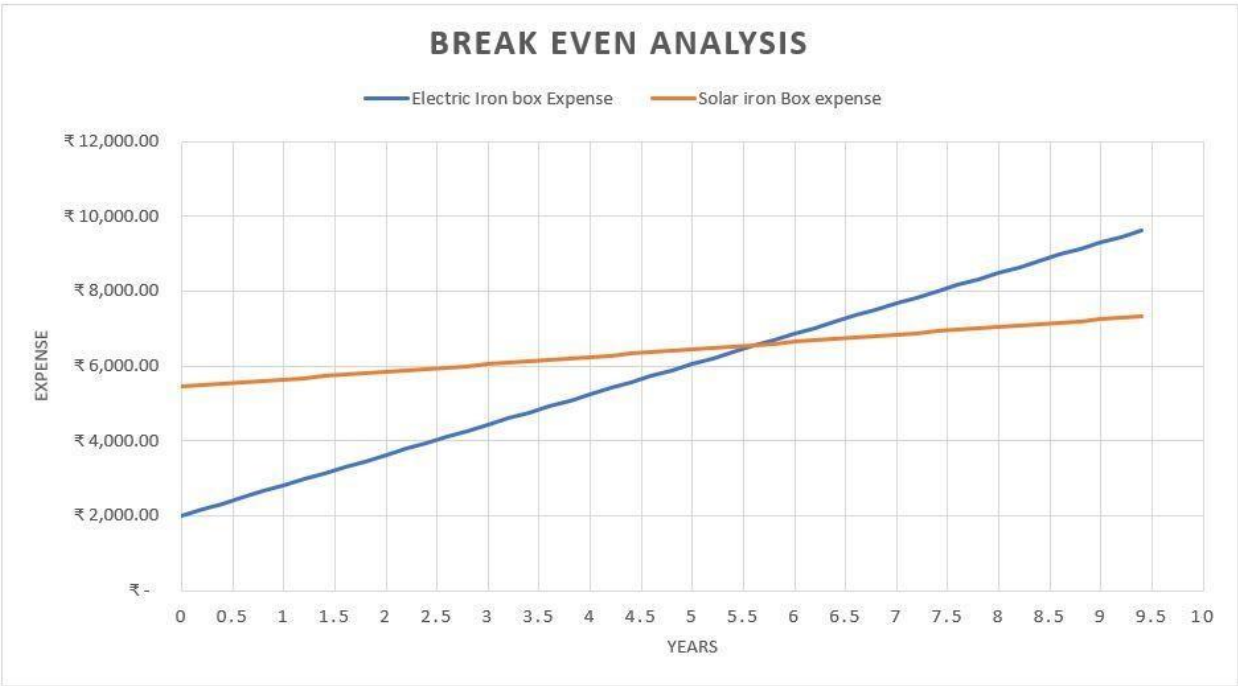

Figure 5.6 Break Even analysis

The operating cost of the electric iron box is at Rs:81/- per month and The operating cost of the solar iron box is at Rs:40/-. But the initial investment of the solar iron box is 3 times that of electric iron box. By calculating the operating cost over the period of 10 years, its evident that after 6 years the solariron box is recovers the initial investment and becomes profitable than the electric iron box

5.10. RESULTS

From the calculations the solar iron box reached it experimental peak temperature of 118°C by from 11 minutes of heating with the efficiency of 50%. With the measured base temperature of 114°C, the iron box sustained its peak temperature of 19 minutes and able to iron spandex, silk, wool, polyester wrinkle free on multiple passes.

6. RESULT SUMMARY, DISCUSSION AND CONCLUSION

6.1. RESULT SUMMARY

From the calculations the solar iron box reached it experimental peak temperature of 118°C by from 11 minutes of heating with the efficiency of 78.47%. With the measured base temperature of 114°C, the iron box sustained its peak temperature of 19 minutes and able to iron spandex, silk, wool, polyester wrinkle free on multiple passes.

Table 6.1 Summary

Temperature of the iron box	Time taken to melt the PCM	Duration the peak temperature sustained	Efficiency	Materials Ironed
114°	11 minutes	19 minutes	78.47%	Wool, Silk, Spandex.

6.2. ADVANTAGES AND DISAVANTAGES

6.2.1 ADVANTAGES

1. The main advantages of the solar iron box is its ability to function without electricity to generate heat. It can be used in region where electricity is not available where people relying on solar panels backed by batteries for electricity where high voltage current is not available to power the electric iron box.
2. Phase Change Material used in Solar iron box are thermal energy storage materials and environment friendly materials. Manufacturing them inlarge scale will have no environmental impacts.
3. The Copper base plate and the insulation provided improved the efficiency of the iron box and preventing convective heat transfer loss.
4. Solar iron box is suitable for mass ironing used in textile industries and cloth packaging industries where wrinkle free cloths are always desired, thereby reducing the electricity cost.
5. Deploying solar iron box in large scale is an indirect method of tackling climate change by reducing our reliance on fossil fuel to generate electricity.

6.2.2. DISADVANTAGES

1. The main disadvantage of solar iron box is that it can be only used during availability of sun light. The time required to melt the phase change material is proportional to the availability of sunlight, its efficiency will be greatly affected other than peak sunlight hours.
2. The solid to liquid phase material possess a unique design challenge of sealing the container to prevent leakage and its property of thermal expansion during different phase influence the designing of the container.
3. The phase change material with have a thermal heating and cooling cycle, which will affect the efficiency of the iron box to retain heat for longer hours.
4. The ability of the clouds to create shades over the iron box during heating will influence the heating time of the iron box.

6.3. FUTURE SCOPE

1. Phase change material with higher melting point and higher energydensity will increase the ironing time of the iron box.
2. Larger solar collector or collector with higher efficiency will reduce the melting time of the phase change material
3. Thermal insulation with better design and different materials can be used to improve the efficiency of the iron box

6.4. CONCLUSION

It is evident that phase change material can certainly be used as latent heat storage system in solar iron box that can be used in day-to-day life in the regions where solar irradiance is in abundance. The regions near equator can benefits greatly from this device. The Erythritol is proven to be a easily available and have the latent heat storage capacity to iron spandex, silk, polyester and wool. Material like cotton and nylon can be ironed by multiple passing of the iron box over the wrinkles.

Materials like paraffins even though easily available and economical feasible, they have very low latent heat storage capacity and have very low discharging times. Salt of amides have the higher melting points and larger heat storage capacity but their prices are considerably higher. The crystalline sugar alcohols line erythritol, sorbitol and xylitol provide great balance between cost and energy storage capacity.

The major design constraint is to prevent the leakage of the liquid phase change material and to preciously calculate the volumetric change of the phase change material during phase transition. The prevailing challenge is to know whether the phase material is completely melted or not without opening the container.

Solid to solid phase change material have the desirable properties of this particular application. These design challenge can to mitigated by using Solid to solid phase change material that provides greater flexibility in designing the container using simple processes that results in reduction in cost of the system.

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