Experimental Investigation of Portable Solar Thermal Energy Storage System using Fatty Acid as a Phase Change Material

K. Gowtham, K. A. Ramesh Kumar, P. Maadeswaran*
Department of Energy Studies,
Periyar University,
Salem-636011, Tamil Nadu, India

Abstract:- **Phase Change Materials plays a vital role in storing of passive solar energy by undergoing thermal and chemical reaction. In this investigation fatty acid is used as a Phase Change Material, it utilizes the properties of latent and sensible heat. Latent heat and sensible heat are important properties of both organic and inorganic materials. Fatty Acid absorbs thermal energy during charging period and releasing in discharging period. Stored energy can be used for further applications and also arrived energy calculation for Charging, discharging and storing period respectively. It shows the performance of fatty acid at different phase and overall efficiency of PCM.**

Key Words - Phase Change Material; Solar Energy; Thermal Energy Storage; Fatty Acid

1. INTRODUCTION

In recent days, demand of Energy to make comfortable Environment for humans has increasing worldwide. Over use of Non-Renewable Energy for heating and cooling increases the level of greenhouse gas and decreases fossil fuel sources [1-2]. Energy storage becomes key issue in engineering applications and facing trouble in storing of Renewable Energy. The important role of the project is to save the energy bydevelopingstorage system. Portable Thermal Energy Storage System (PTESS) using Phase Change Material (PCM) is an effective solution to improve Energy storage.In thermal applications, Latent heat and sensible heat are important tool for storing thermal energy. Thermal Energy Storage using Latent heat in Phase Change Material is widely investigated technology and fast developing research area, and has been relatively extensively used for solar energy storage.Latent heat achieves higher thermal energy storage, simple design of storage system and phase transition of materials occurs in small temperature difference. There are variety of materials are available in the environment to store the thermal energy [3-5].

Phase Change Materials like organic, Inorganic and eutectics are majorly usedto store thermal energy in large rate. Various applications of Phase Change Materials are building energy efficiency, solar water heating, solar air heating, solar cooking and air-conditioning systems [6-10].Using of material which exposes good latent heat (heat of fusion) is very important. One of the most promising organic materials, fatty acid exhibits the desirable characteristics and widely used in recovery of waste solar energy. Normally fatty acid is produced from most available vegetable and animal oil definitely this will reduce shortage issue of fuel sources in world. Due to the property of low temperature latent heat storage and large availability, fatty acid is used in solar drying, solar desalination applications [11-14]. OM-65 type fatty acid is used as a PCM in Portable Thermal Energy Storage System (PTESS).

Design of system is simple and compact. System consists of cylinder, copper tube, used water tank, source water tank, sensors and flow meter. The melting and freezing characteristics of various PCMs which is used as a thermal energy storage are experimentally analysed at different charging and discharging process. And also numerical investigation about phase change of various materials [15-19].Charging, storing and discharging process are carried out in PTESS to determine the performance of material OM-65 by using water as a substance.

Nearly 3.8×10^{23} kW rate of energy radiated from the sun, amount of energy collected by earth is about 1.8×10^{14} kW. 60% of energy reaches the earth surface and remaining 40% of energy reflected back or absorbed by the atmosphere The daily average incident light varying at range between 4-7kWh per m^2 and also it may high or low based on the location. Due to this large energy availability solar water heating systems have been used for more than sixty years [20].Objective of the paper is to collect the solar radiation using a small flat plate collector for storing the energy in a phase change material. The stored energy can be utilized forwater heating that can be used for cooking or drinking purpose. Industries that do not have sufficient space to install solar thermal system can use this work as a model to store thermal energy. In this paper we examined the performanceof phase change material OM-65 at different phase. Instead of using hot water from flat plate collector manual heated water (heater coil) is used for testing the PCM.

2. THERMAL ENERGY STORAGE SYSTEM

Thermal energy storage (TES) can be achieved by cooling, heating, melting, solidifying, or vaporizing a material. This energy can be used as heat when the process is reversed. Properties available to store thermal energy are sensible heat, latent heat and chemical energy. No single material does not satisfy all the required properties for unique storage system. Only an ideal system design make

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up satisfies the condition of proper storage. To satisfy all our needs it is better to adapt TES which has numerous advantages.

2.1. SENSIBLE HEAT STORAGE

Choosing PCMs depends upon the property of sensible and latent heat. Sensible heat storage is nothing but energy can be stored in solid or liquid material by heating and heat will be extracted by cooling the material. There is variety of substance available for heating and cooling the phase change material. The substances like rocks, water, salt, pebbles and refractory. From all these substances water only have highest specific heat and inexpensive. So it used as a substance in large number of thermal energy storage system.The storage materials absorb heat by the conventional heat transfer mechanisms like radiation, conduction and convection. The material cool at night or on cloudy days, the stored heat is released by the same modes heat transfer mechanisms. Sensible heat storage system requires heavy instrument to store the energy.

2.2. LATENT HEAT STORAGE

Latent heat in thermal energy storage system is explained as when heat is supplied to Phase change material or extract from the material it undergoes phase change i.e., solid-liquid or liquid to solid. When the material undergoes solid-liquid transition during heat is stored in the form of latent heat of fusion. Material regains its original state from liquid-solid by reducing temperature or cooling at that time heat extraction takes place in storage system. By implement of phase transition from solid-liquid or liquid-solid stores small latent heat, due to small change in the volume and design of equipment also simple. Large amount of latent heat storage is possible byphase transition from solid-vapor or vapor-liquid. But these kind of transition undergoes large change in volume, big design of system and tedious to operate.

2.3 THERMO-CHEMICAL STORAGE

Thermo-chemical energy storage is used to store the energy by chemical reaction. At that time rising the temperature of thermo-chemical material starts to break the molecular bonds that represents the absorption of heat. To release the absorbed energy when a material undergoes reversible chemical reaction. At reversible reaction the broken molecular bonds will be reforming. In this thermo-chemical material energy storage capacity may vary accordantly due to quantity of material, conversion extent and endothermic heat reaction.

Amongst above mentioned type of storage methods latent heat storage possess more adaptable properties to store thermal energy at very small temperature difference. Phase change materials store thermal energy in the form of latent heat with higher capacity per unit weight. This technology of storing would lead to minimizing the size of HVAC equipment size for average load rather than peak load. Major advantage of choosing latent heat storage method space requirement is much little compared to some other techniques. The important physical properties of latent heat storage system are phase change temperature falls under the operating range, high latent heat per unit mass, high specific heat, high thermal conductivity in both solid and liquid phases, high density, low density variation during phase change, chemical stability, no chemical decomposition, compatibility with container materials, non-poisonous, non-flammable and non-explosive. Latent heat material with solid to liquid phase transformation is selected in portable thermal energy storage system. Because liquid-gas, solid-gas phase transition consumes large amount of heat and designing of system is also complex and impractical for small scale applications.

3. PHASE CHANGE MATERIALS (PCMS)

There are large numbers of PCMs available in any temperature requirement. It has the capacity of changing the phase (from solid to liquid/ liquid to solid) at room temperature and running under zero pollution. Because of good performance in thermal conductivity, use of PCMs to store energy is also going on increasing.Even though large availability of PCMsfor storage application, it does not satisfy the criteria for proper storage. Most abundant kind of Phase Change Materials are organic, inorganic and eutectics. Its properties are explained as follows.

3.1. Inorganic phase change materials

Most abundant inorganic components are salt hydrates andmetallic. The most attractive properties of salt hydrates and metallic are relatively high thermal conductivity, compatible with plastics and only slightly toxic, low heat of fusion per unit weight, high heat of fusion per unit volume and low specific heater relatively low vapour pressure. Many salt hydrates are sufficiently inexpensive for the use of energystorage. Inorganic materials are not used as a PCM in the system, due to the following disadvantages corrosive to most metals, super cooling and phase segregation, loss of thermal performance after large thermal cycles, require high storage capacity and cannot be directly incorporated.

3.2. Eutectics phase change materials

Itmeans mixture of organic-inorganic, organic-organic and inorganic-inorganic which exposes sharp melting point and high volumetric storage density. Eutectics suffer from super-cooling effect and latent heat capacity. It is not suitable material to store thermal energy in small temperature difference. During crystallization materials melts and freeze congruently to form a crystal and has minimum-melting composition of two or more components.

3.3. Organic phase change materials

Organic materials are majorly classified into paraffin and Non-paraffin’s. Esters, alcohol, glycol and fatty acid these kind of Non-paraffin’s are largely available in the market. Paraffin wax is used as a thermal energy storage in large number of energy storage materials it has beneficial consideration like low cost, highly safe, reliable, predictable and less expensive. Due to undesirable properties low thermal conductivity and non-compatibility it is not suitable for portable energy storage.Non-paraffin’s are most available phase change material with highly variable properties. Unlike paraffin wax non-paraffinmaterial have its own properties. Fatty acids possess good thermal conductivity, high latent heat per unit mass and compatibility than other organic materials so it is chosen as a Phase Change Material for PTESS [7].

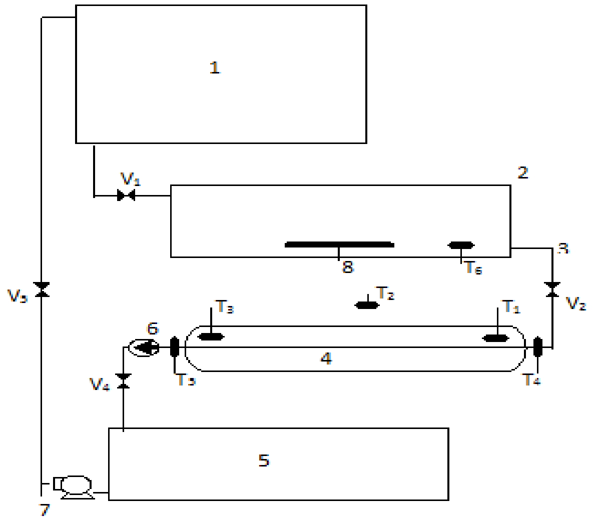
4. PROPERTIES OF FATTY ACID (OM-65)

Phase change material OM-65 is a mixture of organic fatty acids that store large amount of heat energy in the form of latent heat. The material absorb or release energy when it change state from solid to liquid or liquid to solid respectively in small temperature difference. The properties of organic fatty acid mixture OM-65 is given in a Table (1). Organic material-65 (OM-65) has good boiling and melting point these properties are greatly useful to store heat energy at room temperature. And also this material retains its latent heat capacity without any change in physical or chemical properties over thousands of cycles. It stores energy as latent heat in the form of crystalline and white in appearance. PCM has the phase change temperature of about 65˚C, temperature that makes it ideal for many heating/cooling thermal energy applications.

Properties	value	Unit
density in solid state	860	kg/m3
density in liquid state	833	kg/m3
specific heat capacity	0.73	kJ/kgK
heat of fusion	210	kJ/kg
melting temperature	66-68	˚C
freezing temperature	65	˚C

TABLE 1. Properties of OM-65

5. EXPERIMENTAL SETUP



1. Water Tank, 2. Source Heat Transfer Fluid Storage, 3. Copper Tube, 4. Cylinder with PCM, 5. Used Heat Transfer Fluid, 6. Flow meter, 7. Pump, 8. Heater, (T_1 – Front End Temperatue, T_2 – Ambient Temperature, T_3 – Rear End Temperature, T_4 – HTF Inlet temperature, T_5 – HTF Outlet temperature, T_6 – Source HTF Temperature in ^{0}C), V_1 – V_5 Control Valve.

Fig. 1.Schematic diagram of Portable Thermal Energy Storage System

TABLE 2. Instrument components and specifications

Sl. No.	Components	Sub- Components	Specifications	
1	Heat Generating Unit	Source HTF Tank		
		Material	SS-304	
		Capacity	50	(L)
		Length	900	(mm)
		Inner Diameter	240	(mm)
		Insulation cover		
		Material		GI sheet
		Thickness	22	Gauge
		Electric heater		
		Power rating	3000	(W)

2	Energy (heat) storing unit	PCM	Organic fatty Acid	
		Heat Exchanger		
		Heat exchanger tube material	Copper Tube	
		Length	6000	(mm)
		Inner diameter	11.5	(mm)
		Thickness	0.6	(mm)
		PCM holding pipe (shell)		
		Material	SS-304	
		Length	400	(mm)
		Inner diameter	150	(mm)
		Thickness	2	(mm)
		Insulation		
		Material	PUF	
		Thickness	50	(mm)
		Insulation cover		
		Material		GI sheet
		Thickness	22	(gauge)
3	Measuring Instrument	Sensors		
		Number	4	
		Sensor Range	-200 to 600	(^{0}C)
		Flow meter		
		Range	0.5 to 25	(LPM)
4	Accessories	Used HTF tank		
		Material	FRP	
		Capacity	50	L
		Pump		
		Power rating	0.12	(HP)
		Pipe and fittings		
		Pipe material	GI	
		Pipe insulation	Rubber foam	
		Number of valves	5	

Water is the heat transferring fluid (HTF) in the system. While hot water gives heat to the PCM during charging, the cold water absorbed heat from the same PCM during discharging. To supply water for different purposes, two tanks are there in the system. For source of energy, special arrangement has been made within the system. Besides the integrated arrangement, the source water tank is connected with heater coil instead of flat plate solar collector or parabolic trough solar collector for the source of energy.

Different parts of the systems are connected with G.I pipes of ½ inch size. To direct the heat transferring fluid as per requirement several gate valves are fitted in the appropriate locations. Fixing of these components should make in proper manner otherwise leakage of substance occurs. Joints and bends are fixed with proper insulating material to avoid leakage. Some of the precautions should have to follow while working such as check the level of water before switch on the heater. Heater used in the thermal energy storage system is about 3000W so it require 32amps switch otherwise due to power shortage will damages the heater performance. Measure different variables such as temperature and flow rate respective sensors are placed at the targeted points. At certain time air blockage in flow pipe may happens that can resolved by reverse flow of water.

NOMENCLATURE

Sl.No.	**Symbol**	Parameter	Values	Unit
1.	A_i	Copper tube inner cross sectional area	0.308	(m^2)
2.	A_0	Cylinder cover outer cross sectional area	0.3445	(m^2)
3.	D_i	Internal diameter of the copper tube	0.0109	(m)
4.	D_0	Outer diameter of the cylinder cover	0.2438	(m)
5.	h_i	Inner convective heat transfer coefficients	10.131	$(\frac{W}{mk})$
6.	h_o	Outer convective heat transfer coefficients	227.007	$(\frac{W}{mk})$
7.	k_1	Thermal Conductivity of copper tube	390	$(\frac{W}{mk})$
8.	k_2	Thermal Conductivity of PCM	0.2185	$(\frac{W}{mk})$
9.	k_3	Thermal Conductivity of SS	16	$(\frac{W}{mk})$
10.	k_4	Thermal Conductivity of insulation	0.03	$(\frac{W}{mk})$

11.	k_5	Thermal Conductivity of GI	16	$(\frac{W}{mk})$
12.	L_1	Length of copper tube	9	(m)
13.	L_2	Length of PCM layer	0.45	(m)
14.	L_3	Length of SS cylinder	0.45	(m)
15.	L_4	Length of insulation layer	0.45	(m)
16.	L_5	Length of cylinder cover	0.45	(m)
17.	$\dot{m}_{HTF}$	HTF flow rate	-	$(\frac{kg}{sec})$
18.	r_1	Internal radius of copper tube	0.00545	(m)
19.	r_2	External radius of copper tube or internal radius of PCM layer	0.00635	(m)
20.	r_3	External radius of PCM layer or internal radius of SS cylinder	0.07	(m)
21.	r_4	External radius of SS cylinder or internal radius of insulation	0.071	(m)
22.	r_5	External radius of insulation layer or internal radius of cylinder cover	0.121	(m)
23.	r_6	External radius of cylinder cover	0.1219	(m)
24.	L	Length of the cylinder	0.9	(m)
25.	$R_{1,2,3}$	Thermal Resistance during charging, storing, discharging	-	–
26.	$q_{1,2,3}$	Energy loss from the system at charging, storing, discharging	-	$\left(\frac{W}{m}\right)$

6. WORKING

Totally three process were carried out in portable energy storage system to analyse the energy transfer between HTF and Phase change material and also to calculate efficiency. The three process are charging, storing and discharging.

6.1. Charging Period

The working of the system starts with filling of water in the source HTF storage tank. Once this tank is filled then the heat is supplied to the water by switching on the electric heaters. Once water reaches the required temperature in the HTF source tank then the appropriate valves are open and allow the hot water to flowthrough the heat exchanger of the targeted PCM cylinder. The hot water gives heat to the PCM by the process of convection and conduction on its way of flow from one end to other of the heat exchanger. This stage in which the PCM accrued energy is known as charging stage. Energy input to the system calculated from Eq. (1) and the loss occurred from the storage system at charging state obtained from the Eq. (3).After giving heat to PCM the water get accumulated into the used HTF storage tank. Hot water keeps flowing continuously through the heat exchanger till the PCM charged fully. Once the PCM stored energy up to the maximum level the hot water is stopped by closing the appropriate valves. With the stop of flow of hot water the charging stage of the system gets completed. Finally Energy accumulated in phase change material and total energy at end of charging period are calculated from Eq. (2) and Eq. (4).

Here, energy input during charging,

$$E_{in}=m_{HTF}C_{HTF}(T_4-T_5)\times t\ (J) \quad (1)$$

Energy accumulated during charging,

$$E_{Chr}=E_{in}-E_{loss,1} \quad (2)$$

Here,

$E_{loss,1}$: Loss of energy during Charging period

$$E_{loss,1}=q_1\times L_4\times t\quad (J) \quad (3)$$

$$q_1=\frac{T_{pcm}-T_2}{R_1}$$

$$R_1=\frac{1}{h_iA_i}+\frac{\ln(\frac{r_2}{r_1})}{2\pi k_1L_1}+\frac{\ln(\frac{r_3}{r_2})}{2\pi k_2L_2}+\frac{\ln(\frac{r_4}{r_3})}{2\pi k_3L_3}+\frac{\ln(\frac{r_5}{r_4})}{2\pi k_4L_4}+\frac{\ln(\frac{r_6}{r_5})}{2\pi k_5L_5}+\frac{1}{h_0A_0}$$

Total Stored at the end of charging

$$E_{total,Chr}=\text{Sum of } E_{Chr} \quad (4)$$

6.2. Storing period

Once the PCM is fully charged, the energy ideally stays inside the PCM until it is extracted. However, since the PCM is at higher temperature energy keeps losing to the environment. Depending upon the PCM temperature and the insulation use in the system the amount of energy loss vary from system to system. Like the charging period, energy stored at every time interval during storing period are calculated by subtracting of energy loss it is expressed in Eq. (5) and Eq. (6). The complete ability of portable energy storage system comes to know only after analysing of storage process. Total energy retained at the end of storing process are calculated from Eq.(7).

Energy stored in TES at during storing,

$$E_{Str}=E_{total,Chr}-E_{loss,2} \quad (5)$$

Here,

$E_{loss,2}$: Loss of energy during storing period

$$E_{loss,2}=q_2\times L_4\times t\quad (kJ) \quad (6)$$

$$q_2=\frac{T_{pcm}-T_2}{R_2}$$

$$R_2=\frac{\ln(\frac{r_4}{r_3})}{2\pi k_3L_3}+\frac{\ln(\frac{r_5}{r_4})}{2\pi k_4L_4}+\frac{\ln(\frac{r_6}{r_5})}{2\pi k_5L_5}+\frac{1}{h_0A_0}$$

Energy stored in TES at the end of the storing,

$$E_{total,str} \quad (7)$$

6.3. Discharging Period

The next step of the experiment is extraction of heat from the PCM. This step is also known as discharging of PCM. To discharge the PCM cold water is sent through the heat exchanger of PCM cylinder. The cold water can also be sent from the cold HTF tank directly by using the pump. The cold water, while flows from one end to the other of the heat exchanger absorbed heat from the PCM. After absorbing heat the water get accumulated in the used HTF tank. Flow meter and Temperature sensor are fitted in this unit. From thisequipment water flow rate, temperature values are noted down at different condition of the system. Eq. (8) is used to calculate the amount of energy recovered at discharging process. Energy loss at every time interval of discharging period calculated from Eq. (10). Loss of energy from the system is reduced by installing of proper insulation material. Even though with consideration of resistance only energy loss of system is calculated. Amount of energy at end of every time interval is calculated from Eq. (9). And finally total energy discharged during discharging period find out from Eq. (11).

Energy recovered from TES during discharging,

$$E_{dis} = m_{HTF,dis} \times C_{p,HTF}(T_4 - T_5) \times t \text{ (kJ)} \quad (8)$$

Amount of energy available to discharge Or Energy available at the end of storing period

E_3=Energy available at the end of the storing period - $(E_{dis} + E_{loss,3})$ (9)

$$E_{loss,3} = q_3 \times L_4 \times t \quad \text{(kJ)} \quad (10)$$

$$q_3 = \frac{T_{pcm} - T_2}{R_3}, R_3 = \frac{\ln(\frac{r_4}{r_3})}{2\pi k_3 L_3} + \frac{\ln(\frac{r_5}{r_4})}{2\pi k_4 L_4} + \frac{\ln(\frac{r_6}{r_5})}{2\pi k_5 L_5} + \frac{1}{h_0 A_0}$$

Energy Available at the End of discharging

$E_{final,dis}$ (Energy retains in PCM after the period of discharging)(11)

7. RESULTS AND DISCUSSION

The observed and calculated values during charging, storing and discharging are explained in below tables. It contains raise of PCM temperature, energy calculation by fixing constant water flow rate. Readings are noted at regular time interval shows the variation in energy absorption and release during charging and discharge period respectively. Overall efficiency of thermal energy storage system also calculated using the values from the charging and discharging process. That implies the performance of phase change material used in the instrument. The graph plotted shows the average temperature variation at batch wise process.

7.1. Effect of PCM at charging period

Onfirst day charging experiment was done by passing source hot water of about 95°C temperature. At the time of charging period temperature of source water should maintained in the range of 100°C to 85°C otherwise it consume enormous amount of water to charge the Phase Change Material. High temperature water transfer more heat though the copper pipe with short period of time. In case availability of source water to heat PCM is less than 50°C means it consumes more time and water circulation. In portable thermal energy storage system water heater is used to maintain the source water temperature during the process of charging so maintaining of source water is easy. Various collectors are largely available in current environment to produce source hot water. Mass flow rate (m_{HTF}) play important role in both charging discharging process. Only at minimum flow rate of source water over the PCM cause quick charge than maximum flow rate of hot water. The charging process experiment of OM-65 material was done up to the phase change of material occurs. If the material attains it melting point of about 68°C then comes to know the material reached maximum energy absorption. OM-65 material quickly reaches its boiling point at short change in temperature. Energy absorption at every time interval of phase change material at charging period was tabulated with maintain same flow rate refer Table (3).

Table 3. Observed and calculated values at charging period (Day – 1)

Time	m_{HTF}	T_6	T_s	T_2	T_4	T_5	T_1	T_3	T_{PCM}	E_{in}	$E_{Loss,1}$	E_{Ch}
2.00 pm	-	40.9	33.1	33.5	-	-	-	-	-	-	-	-
2.10 pm	0.212	94	33.1	33.5	93.1	79.7	34.1	34.6	34.35	69.45	1.771	67.679
2.20 pm	0.212	93.6	34.9	33.5	92.8	80.7	36.3	33.3	34.8	62.712	1.794	60.918
2.30 pm	0.212	90.2	37.6	33.5	88.4	78.1	38.4	35.8	37.1	58.568	1.924	56.644
2.40 pm	0.212	88.5	41.3	33.5	86.7	76.2	43.7	37.7	40.7	60.123	2.099	58.024
2.50 pm	0.212	88.3	42.8	33.5	86.1	75.2	45.2	39.6	42.4	56.49	2.186	54.304
3.00 pm	0.212	87.1	43	33.5	85.3	73.5	47.7	45.9	46.8	61.159	2.413	58.746
3.10 pm	0.212	87.6	43.4	33.5	85.7	74.3	51.4	47.3	49.35	59.086	2.547	56.539
3.20 pm	0.212	86.9	44.5	33.5	84.2	72.9	55.2	51.7	53.45	58.568	2.756	55.809
3.30 pm	0.212	86.5	46.7	33.5	83.4	72.3	59.7	57	57	57.53	2.939	54.591
3.40 pm	0.212	86.4	47.8	33.5	82.9	71.9	63.3	59.2	61.25	57.013	3.159	54.471

And total energy stored at the end of charging period also calculated that is sum of all energy added at specific time interval.Complete energy input during charging period is 699.69 kJ. Phase material absorb energy from input of about 577.72 kJ at the end of charging period with considering energy loss.

Total Energy Stored in PCM during Charing

$E_{total,Ch}$ = 577.725 (kJ)

Energy input during Charging$E_{in,total}$ = 600.699 (kJ)

7.2. Effect of PCM at storing period

To analyse storage time period of phase change material this process is taken into consideration. Main purpose of portable thermal energy storage instruments is to store heat. Periodic energy calculation at the time of storing process shows the energy loss over the period of 18hours. At the time 4.00pm (day one) to 10.00am (day two) leave the instrument in the undisturbedstate.Refer the observed readings at storing period in Table (4). There is minimum range of temperature loss occurs at this complete time period.

Table 4. Observed readings at storing period

Time	Total Time gap in hrs	T_1	T_3	T_{PCM}
4.00 pm	0	62.9	58.6	60.75
8.00 am	16	55.8	48	51.9
10.00 am	2	54.1	47.6	50.85

Table 5. Average temperature decrease value during storing period

PCM Temperature drop in 18hrs	9.9	PCM Temperature drop in 2hrs	1.05

At the end of charging period average temperature of phase change material is 60.75°C after eighteen hours it reaches about 50.85°C.In order to calculate average decrease inPCM temperature during this over all period of night time simplydividing by average of total time period or change in value of temperature two hours.Average value of complete storing was shown in the Table (5).

Average temperature decrease prediction is used to calculate the energy loss at every time interval refer Table (6). Finally after loss of energy about 214.82 kJ occurs at complete time of eighteen hours. PCM retains 362.9 kJ of energy to discharge with elimination of energy loss.

Table 6. Calculated values during storing period

Time	T_2	Temp drop in Every 2hrs	T_{PCM}	q_2	$E_{Loss,2}$	E_{str}
-	-	-	-	-	-	577.725
04.00 pm	34.2	0	60.5	4.028	26.106	551.618
06.00 pm	34.2	1.05	59.7	3.869	25.074	526.545
08.00 pm	34.2	1.05	58.65	3.710	24.041	502.50
10.00 pm	34.2	1.05	57.6	3.550	23.004	479.5
12.00 am	34.2	1.05	56.55	3.391	21.976	457.524
02.00 am	34.2	1.05	55.55	3.239	20.976	436.548
04.00 am	34.2	1.05	54.5	3.080	19.961	416.587
06.00 am	34.2	1.05	53.45	2.921	18.928	387.659
08.00 am	34.2	1.05	52.4	2.761	17.896	379.763
10.00 am	34.2	1.05	51.35	2.602	16.863	362.9

Energy Available at the end of Storing Period

$E_{total,str}$ = 362.9 (kJ)

7.3. Effect of PCM at Discharging Period

Table 7. Calculated values during discharging period (Day – 2)

Time	m_{HTF}	T_2	T_s	T_4	T_5	T_1	T_3	T_{PCM}	$E_{Loss,3}$	E_{dis}	E_3
-	-		-	-	-	-	-	-	-	-	362.9
10.10 am	0.212	34.2	34.9	34.4	43.3	54.1	47.6	50.85	1.347	46.12	361.553
10.20 am	0.212	34.2	34.9	34.6	42.2	52.7	47.5	50.1	1.286	39.39	314.147
10.30 am	0.212	34.2	34.9	35.1	41.4	50.4	47.3	48.85	1.184	32.65	273.573
10.40 am	0.212	34.2	34.7	34.6	40.4	48	47.1	47.55	1.077	30.06	239.846
10.50 am	0.212	34.2	34.8	34.8	39.2	45.5	43.7	44.6	0.835	22.805	208.951
11.00 am	0.212	34.2	34.6	35.2	39.1	42.5	41.1	41.8	0.606	20.213	185.54
11.10 am	0.212	34.2	34.6	35.3	38.9	42.9	40.3	41.6	0.589	18.65	165.269
11.20 am	0.212	34.2	34.3	35.1	38.2	41.2	39.8	40.5	0.499	16.06	146.12
11.30 am	0.212	34.2	34.2	35.2	38.2	39.7	37.6	38.65	0.348	15.57	129.712
11.40 am	0.212	34.2	34.1	35.3	37.7	38.2	37.3	37.75	0.274	12.95	113.868

On second day discharging process started after completion of storing period analysis. In the discharging period rate of decrease in PCM temperature come to know. At the starting stage energy loss occurs in lower range that implies phase change of material from liquid to solid. After that rate of discharge is faster and also change of liquid phase or release of boiling point temperature occurs. Like charging process discharging of PCM also takes place with same flow rate of about 0.212 kg/sec.

PCM is experimented under same flow rate to find out the temperature variation. If the experiment of charging and discharging with different mass flow rate of water means then that cause major variation in PCM temperature. Keeping same rate of water flow is efficient way to analyse the performance of PCM. 362.9 kJ of energy is available to release from the system during discharge and values of discharge period are shown in Table (7).

Energy discharge from thermal energy storage system is calculated at regular time interval. After 80 minutes rate of discharge is slower, up to 140 minutes readings noted down. At the end of discharging process total energy recovered from the system is about 254.468 kJ

Energy recovered during discharging of PCM

$$E_{dis,total} = 254.468 \text{ (kJ)}$$

7.4. Overall system efficiency

The overall system efficiency is also the first law efficiency of the TES system.To quantify the effectiveness

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of a system in converting the heat energy input to useful energy output. Overall efficiency of the system is expressed as

$$\eta_{overall} = \frac{\text{Energy recovered from TES during discharging}}{\text{Energy input during charging}}$$

Overall efficiency of OM-65 phase change material used in the portable thermal energy storage system is 42.33% as shown in the below calculation.

$$\eta_{overall} = \frac{E_{dis,total}}{E_{in,total}} = \frac{254.468}{600.699} = 42.33\%$$

8. GRAPH

Graph was plotted between Average PCM Temperature vs. Time duration. In that, Fig. (2) Shows temperature increase and decrease in during charging and discharging period respectively. At the time of charging periodically temperature starts to rise from minimum level of about 35 ^{0}C to 65 ^{0}C. In depth analysis of charging curve shows that from starting to end only moderate rise in temperature at a constant flow rate of about 0.212 kg/sec. if flow rate of water passing through the Phase Change Material increased means time required to attain maximum temperature of about 65^{0}C or latent heat temperature will increase and also need little more hot water. If availability of source hot water for charging PCM at very high temperature more than 100 ^{0}C means material attains its melting point in short period of time. That depends upon type of collectors attached with thermal energy storage system to heat the source water.

Fig. 2.Graph to show temperature variation at charging and discharging period

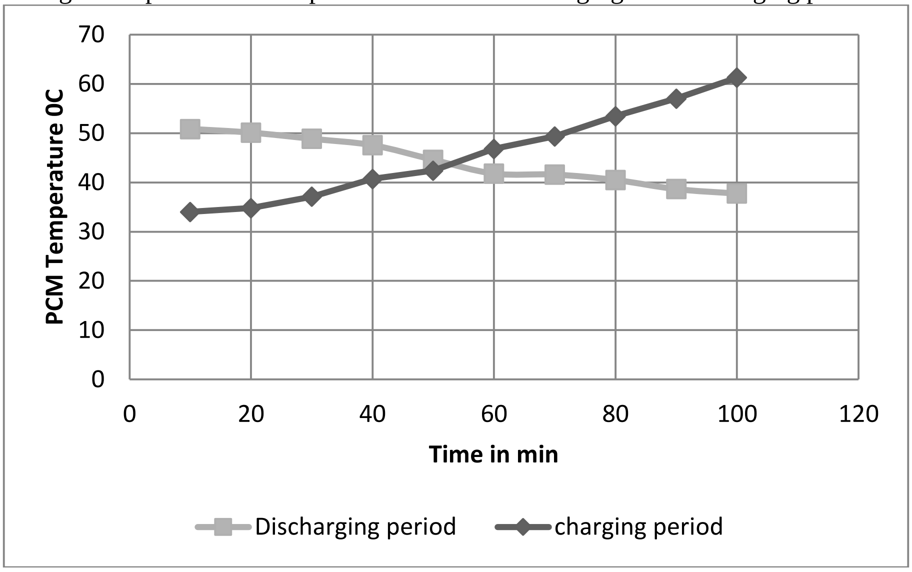
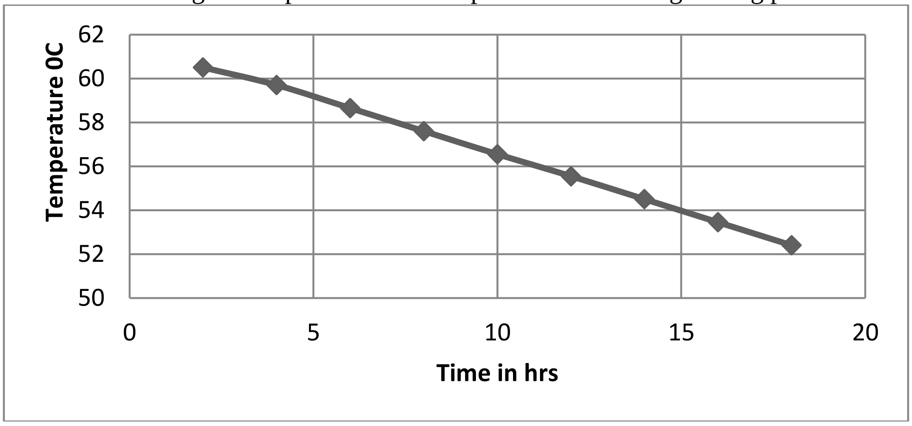


Fig. 3. Graph shows the temperature loss during storing period



From discharging curve,we come to know that the temperature of PCM start to decrease from available energy. While during starting stage of the discharging process rate of decrease in energy from Phase Change Material is slow. After it reaches the temperature 50°C loss of energy from PCM is in higher order. And also fast rate of temperature decrease will happen when flow rate of cold water though the material increase. And Fig. (3) Represents loss of PCM temperature at storing period. Time duration for storing period is nearly 20 hours. Over this complete period of storing 8°Ctemperature drop in organic material-65. There is no major drop in temperature of PCM it reaches melting point of about 68°C means complete phase change of material occurs and minimum loss of energy during storing period also able to avoid.

9. CONCLUSION

Useful energy on demand is a prominent constraint in case of solar thermal energy technology. However, the integration of Portable thermal energy storage system with the modern solar thermal technology has increased their acceptance. The phase changing material based latent heat storage systems are most promising technologies. This experimental study was conducted on the Phase Change Material organic fatty acid OM-65. The results of the study summarized that 254.468 kilo Joules of energy can be harnessed and stored using fatty acid. Efficiency during charging period is 96 percent and overall efficiency of Portable Thermal Energy Storage System is 42.33 percent. The overall efficiency gets reduced due to little defect in energy transfer between phase change material and HTF (fatty acid and water)during the process of discharge. Though, future researches are going to latent heat storage system that extractsmuch best possible results from this technology with minimum efforts.

Increase of the time delay between the impose conditions (or external weather conditions) and the internal conditions. This Portable Thermal Energy Storage System, allows to store heat during the day time and release during the night, leading to low daily temperature swing.This renewable energy system is developed to produce hot water for small scale applications using flat plate collector.By implementing these kinds of project we can greatly reduce energy demand and increase the renewable energy production in future.

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