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Latent Heat Storage System: A Panacea to Address Energy Needs

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Abstract - The need for alternative sources of energy is of vital importance in the present time when the world's non-renewable energy sources are rapidly getting depleted. The reason for this depletion is that humans are utilizing the energy at a much faster rate than is being produced. Additionally, in some cases, it is inevitable that the primary source of certain forms of energy will just get exhausted. Clearly this is a problem that requires a lot of attention and it becomes imperative that effective solutions are devised. Solar energy is one such alternative form. It is renewable, environment friendly, easily available and free of cost. One major drawback is that solar energy is available for use only during the day. Hence it becomes necessary that a way is found by which we can utilize solar energy even during the absence of the Sun. This project attempts to do just that. The objective of this project is to utilize solar energy during the day and store some of the unused energy for use at night. There are two ways in which thermal energy can be stored, the first being via the sensible heat of a material and the second being via the latent heat. Of course, it is possible that a combination of the two is also used.

Keywords : alternative, concentric, lauric, night, solar, thermal.

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LATENT HEAT STORAGE SYSTEMA PANACEA TO ADDRESS ENERGY NEEDS

Strictly as per the compliance and regulations of :

Latent Heat Storage System: A Panacea to Address Energy Needs

Ujjwala Sharma [α], Vaibhav Dixit [σ] & Prof. D.V. Mahindru [ρ]

Abstract - The need for alternative sources of energy is of vital importance in the present time when the world's non-renewable energy sources are rapidly getting depleted. The reason for this depletion is that humans are utilizing the energy at a much faster rate than is being produced. Additionally, in some cases, it is inevitable that the primary source of certain forms of energy will just get exhausted. Clearly this is a problem that requires a lot of attention and it becomes imperative that effective solutions are devised. Solar energy is one such alternative form. It is renewable, environment friendly, easily available and free of cost. One major drawback is that solar energy is available for use only during the day.

Hence it becomes necessary that a way is found by which we can utilize solar energy even during the absence of the Sun. This project attempts to do just that. The objective of this project is to utilize solar energy during the day and store some of the unused energy for use at night. There are two ways in which thermal energy can be stored, the first being via the sensible heat of a material and the second being via the latent heat. Of course, it is possible that a combination of the two is also used.

Additionally, due to the plethora of applications of solar energy, this project limits the use of solar energy for cooking purposes only. This project employs a parabolic trough collector to capture solar energy and phase change materials to store that energy. The captured energy is then retrieved when required during the night. Finally, the effectiveness of the project is determined by the maximum surface temperature achieved on the cooking unit due to the energy extracted from the Phase Change Material (PCM).

After conducting the experiment, a water boiling test was performed on the flat plate cooking unit. From the results, it was concluded that Lauric acid can be effectively used as a phase change material for solar cooking application. Cooking using solar energy is extremely beneficial as it is inexpensive and solar energy is easily available. Several types of solar cookers have been developed. These can be classified broadly under two headings namely concentration type and box type. In the concentration type solar cooker parabolic or spheroid reflectors are used with the cooking pot placed at their sun ray focal point. In the box type solar cooker, the solar radiation direction enters through the glass window to cook the food. The experimental set up was created in-house and extensive experimental work was carried out to demonstrate the basic concepts. The real pictures of the set up have been presented in the Project report[1].The detailed theoretical analysis has been carried and the results indicate that the concept if implemented can address the energy needs of a country like India which has enormous resources of Solar Energy that too for a longest period. This acts as panacea to address the energy needs of developing country like India.

Keywords : alternative, concentric, lauric, night, solar, thermal.

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I. Introduction

Nobel Laureate Richard E. Smalley outlined humanity's top ten problems for the next 50 years in a talk given to the Massachusetts Institute of Technology Enterprise Forum. According to professor Smalley, energy was the biggest problem that humanity would face for the next 50 years. Some of the other problems included water, food, the environment and poverty. It becomes quite clear that some of these problems can be solved to some extent by focusing on improving the energy crisis that the world faces. For instance, utilizing renewable sources of energy in an inexpensive manner would lead to reduced expenditure on energy production. The savings garnered by doing so could be utilized to solve problems related to food and water. Thus, it becomes very evident that energy constitutes one mammoth problem for humanity and becomes an issue of highest priority when it comes to seeking a solution. The energy scenario in India is not very different from that of the rest of the world. Up till the end of 2009, data reveals that 64% of the installed power generation capacity comes from thermal energy. Nuclear energy contributes 2.6% whilst renewable sources of energy contribute the rest. This clearly indicates that thermal energy is India's backbone when it comes to energy sources used. Unfortunately, this is not a good sign for the country. One reason for this is that most of the raw material used to generate thermal energy is not of good quality. Take coal as an example. The coal available in India contains about 45% ash. This is not desirable and it only prevents the efficient production of thermal energy.

II. Description

a) Parabolic Trough Collectors

A parabolic trough collector is a type of solar thermal energy collector. It is constructed as a long parabolic mirror with a collector tube running its length at the focal point. Sunlight is reflected by the mirror and concentrated on the collector tube. A heat transfer fluid, also frequently referred to as working fluid in this report, runs through the collector tube to absorb the thermal energy from concentrated sunlight Parabolic trough collectors are designed to reach temperatures over 100 degree C and up to 450 degree C and still maintain a high collector efficiency by having a large solar energy collecting area, called aperture area, but a small surface where the heat is lost to the environment (absorber surface). The concentration ratio, defined as the ratio of the aperture area to the absorber surface, determines the temperature up to which the heat transfer fluid can be heated in the collector tube.

b) Operating Principle

The reflecting surface of the parabolic trough collector has a parabolic cross section. The curve of the parabola is such that light traveling parallel to the axis of a Parabolic mirror will be reflected to a single point from any place along the curve. Since the Sun is at a very large distance, the solar light coming directly is essentially parallel making the sunlight concentrate at the focal point. A parabolic trough collector extends the parabolic shape to three dimensions along a single direction, creating a focal line along which the absorber tube is run. This is shown in Figure 2.1.

c) Tracking

Parabolic trough collectors – like other solar concentrating systems – have to track the Sun. The troughs are normally designed to track the Sun along one axis oriented in the North-South or East-West direction. Such systems are called single axis tracking systems. Figure 2.2 shows such a system in which the collector is oriented along the North South direction, thereby enabling tracking of the Sun in the East-West direction.

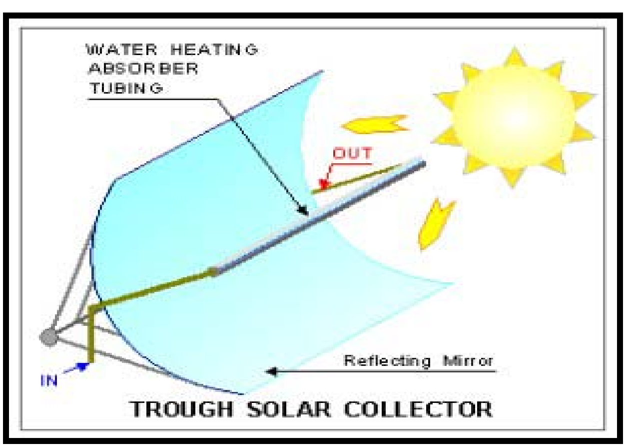
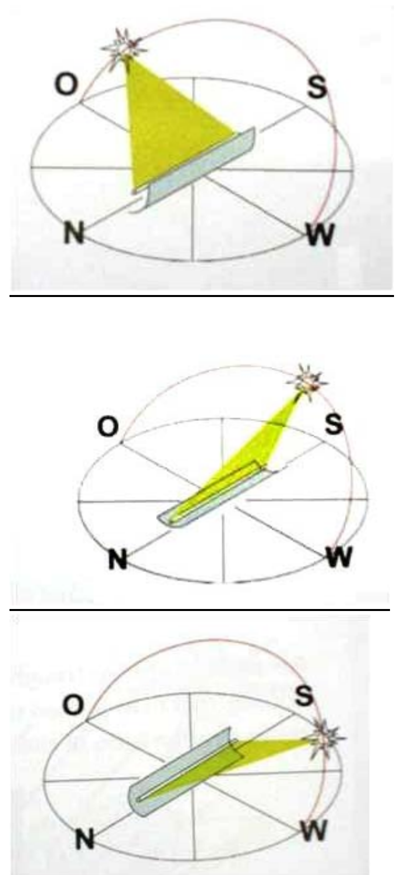


Figure 2.2 : Parallel sun rays being concentrated onto the focal line of the collector



d) Phase Change Materials

A phase change material (PCM) is a substance with a fairly high heat of fusion capable of storing and releasing large amounts of energy. These substances have high heat retention capabilities in that they do not lose the heat absorbed quickly. Heat is absorbed or released as the material changes from the solid phase to the liquid phase and vice versa.

As a result, PCMs are also referred to as latent heat storage materials. Figure 2.3 on the following page shows the simplified heating curve for a phase change material.

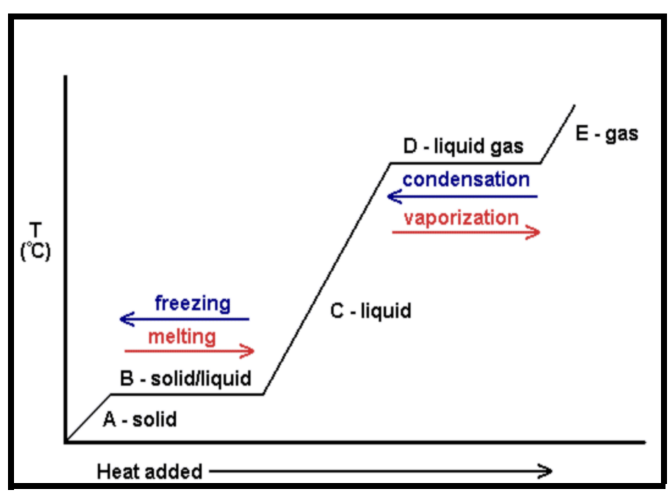


Figure 2.3 : Heating curve for a phase change material

i. *Properties*

Phase change materials have certain properties which make them desirable for latent heat storage in thermal storage applications. Some of these properties are listed on the following page.

(1) High latent heat of fusion per unit volume.

(2) High specific heat to provide additional sensible heat storage.

(3) High thermal conductivity of both solid and liquid phases to assist the charging and discharging of energy.

(4) Small changes in volume on phase transformation to reduce containment problems.

(5) High rate of crystal growth so that the system can meet demands of heat recovery from the storage system.

(6) Chemical stability

(7) No degradation after a number of solidification/melting cycles.

(8) Non corrosive, non toxic and non flammable.

(9) Easy availability and fairly low cost.

e) *Classification*

Phase change materials can be broadly classified into three types namely organic, inorganic and eutectic. Organic phase change materials are generally paraffin and fatty acids. Inorganic PCMs are salt hydrates while eutectics include organic-organic, organic inorganic and inorganic-inorganic compounds. The phase change material used in this project is LAURIC ACID an organic compound. Figure 2.4 shows the chemical structure of LAURIC ACID.

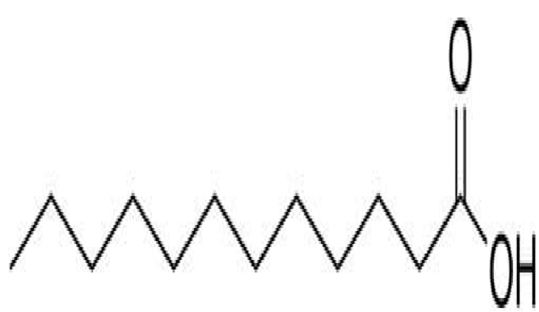


Figure 2.4 : Chemical structure of Lauric Acid

f) *Energy Storage Systems*

There are two ways in which thermal energy can be stored, the first being via the sensible heat of a material and the second being via the latent heat. Of course, it is possible that a combination of the two is also used.

i. *Sensible Heat Storage*

In sensible heat storage, the substance storing energy is heated causing its temperature to rise. The heat added as the temperature increases is called sensible heat. Similarly, when heat is removed, the temperature falls and this heat is also called sensible heat. Thus, in sensible heat storage, heat added during charging or removed during discharging is accompanied by a change in temperature. The stored energy can be calculated by taking the product of mass, average specific heat capacity and the temperature change.

ii. *Latent Heat Storage*

In latent heat storage, the substance storing energy is heated causing it to change its phase. Since the heat absorbed or released results in a change in phase, there is no temperature change accompanying the process. In this case, the stored energy can be calculated by taking the product of the mass and the latent heat capacity of the substance.

iii. *Sensible heat storage versus latent heat storage*

Amongst the two thermal heat storage techniques, latent heat thermal energy storage is particularly attractive due to its ability to provide high energy storage density and its characteristic to store heat at a constant temperature corresponding to the phase transition temperature of the phase change material.

III. Riview of Previous Work

3.1Vast amount of research has been done on the collection, storage and applications of solar energy. Papers have been published regarding the same. Given below are some of the papers that were consulted. Based on the information that each paper provided, the drawbacks related to cooking using solar energy were identified. An attempt was made to reduce these in this project.

Felix Regin, S.C. Solanki, J.S. Saini (2005) conducted an experiment analyzing the melting behaviour of paraffin wax as a phase change material (PCM) encapsulated in a cylindrical capsule, used in a latent heat thermal energy storage system with a solar water heating collector. The heat for melting of the PCM in the capsule was provided by the hot water surrounding it.

Buddhi and Sahoo (1997) have studied the use of stearic acid (melting point 69°C) as a PCM for heat storage.

Buddhi and Sahoo filled the PCM below the absorbing plate of the cooker. In such a design, the rate of heat transfer from the PCM to the cooking pot during the discharging mode of the PCM was found to be slow, and more time was required for cooking an evening meal.

Peng Ye and Thomas Byron (2008) showed that Lauric acid has a high tendency to crystallize when cooled from its molten state. It has a polymorphic crystalline structure and consists of 3 polymorphs (Alpha, Beta and Gamma).

Bo Tong, Rui-Bin Liu et al. (2010) used a differential scanning calorimeter to perform the thermal analysis of Lauric acid under high purity nitrogen (99.99%) with a flow rate of 40 mL/min. 3 to 5 mg of the sample was used and experiments were conducted in an alumina crucible. The heating rate used was 10 K/min. TG measurements of the sample were carried out by a thermogravimetric analyzer under N2 with a flow rate of 40 ML/min and at heating rates of 5, 10, 15, 20 and 25 K/min. The temperature range used was 300 K to 800 K. The DSC curves revealed information about the melting point of Lauric acid while TG-DTG curves showed its thermo stability. It begins to lose mass at about 540 K, reaches a maximum rate of mass loss at about 650 K and completely loses its mass when the temperature reaches 700 K. The peak temperature of decomposition was also shown to increase with heating rate.

Tyagi .S.K et al. (2006) made an exergy analysis and parametric study on concentrating type solar collectors. The exergetic performance of concentrating type solar collector is evaluated and the parametric study is made using hourly solar radiation. Most of the performance parameters, such as, the exergy output, exergetic and thermal efficiencies, stagnations temperature, inlet temperature, ambient temperature etc. increase as the solar intensity increases. The performance parameters, mentioned above, are found to be the increasing functions of the concentration ratio but the optimal inlet temperature and exergetic efficiency at high solar intensity are found to be the decreasing functions of the concentration ratio.

Sharma et al. (2000) designed and developed a cylindrical PCM storage unit for a box type solar cooker to cook food in the late evening. Since this unit surrounds the cooking vessel, the rate of heat transfer between the PCM and the food is higher, and cooking can be faster. They reported that by using 2.0 kg of acetamide (melting point 82°C) as a latent heat storage material, a second batch of food could be cooked if it is loaded before 3:30 pm during winter. They recommended that the melting temperature of a PCM should be between 105 and 110°C for evening cooking.

From this literature review, it could be observed that solar energy was being utilized mainly during the day. In order to store solar energy, the usage of suitable phase change materials was required. These phase change materials required high heat capacities and high melting points and stored solar energy in the form of latent heat. Some of the papers described the properties of Lauric acid and it was found that most of the properties were characteristic of a good phase change material. Hence, this project attempts to test the performance of Lauric acid as a PCM. The design process for efficient cooking units was also learnt.

IV. Experimental Setup and Basic Operation

Figure 4.1 shows the schematic of the experimental setup

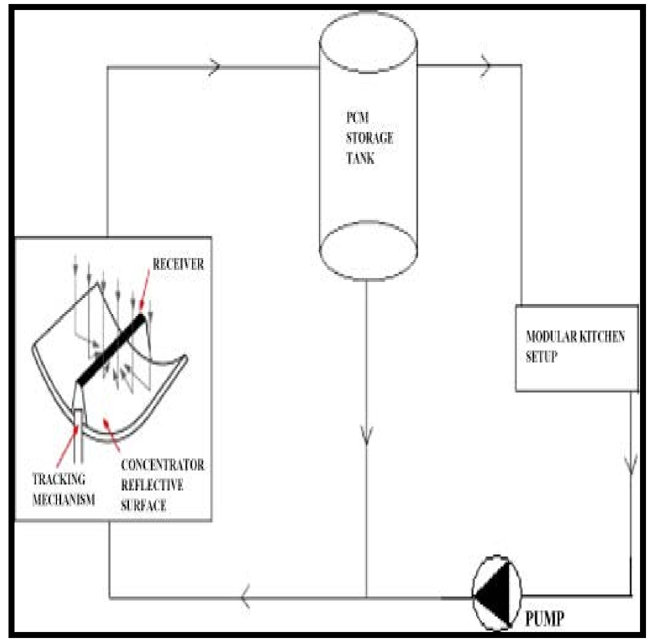


Figure 4.1 : Schematic of the experimental setup

By the proper control of the valves, the following operations are possible

1. **Day operation with cooking:** During the day, the working fluid passes through the Parabolic Trough Collector (PTC) and absorbs the solar energy. A part of the hot fluid then passes through the bottom of the PCM Tank and leaves from the top. In the PCM Tank, heat is absorbed by the PCM thereby cooling the working fluid. The remaining hot fluid can be used for cooking during the day by passing it through the cooking unit. The working fluid leaving the cooking unit then meets that leaving the PCM Tank and the fluid is then pumped back through the PTC.
2. **Day operation without cooking (charging process):** In this, all of the working fluid, after absorbing heat in the PTC, is passed through the PCM Tank for storage. The 18 working fluid leaving the PCM Tank is then pumped back into the PTC and the cycle continues.
3. **Night operation (discharging process):** Here, the PTC is cut-off from the circuit and the cooled working fluid is passed through the PCM Tank. The PCM balls located in the tank lose the heat that they captured during the day to the working fluid. The hot working fluid then leaves the PCM Tank and passes through the cooking unit, thus enabling cooking at night. The fluid leaving the cooking unit is then circulated through the PCM Tank once again and the process is continued till required.

a) Individual Component Specifications

In this article, the specifications of each of the components used are provided.

i. *Concentric Trough Collector*

Figure 4.2 shows a photo of the parabolic trough collector. Its specifications are as follows:

(1) Collector aperture area = 0.7088 metre square

(2) Collector length = 0.98cm

(3) Support structure materials = Cast iron

Figure 4.2

ii. *PCM Storage Tank*

The photos in Figures 4.3 show the PCM tank. Its specifications of the PCM tank are as follows:

(1) Height of PCM tank = 31.4 cm

(2) Diameter of tank = 10 cm

Figure 4.3

iii. *Pump*

(1) Speed = 220rpm

(2) Capacity = 2.4 W

(3) Head = 3.2m (maximum)

iv. *Cooking Units*

Diameter of Inner bowl = 20cm
Depth of Bowl = 15cm

b) Working of Cooking Units

In order to describe how the cooking units work, we use the bowl type cooking unit as a specific example. The working of the flat plate cooking unit is based on the same principle.

Lauric acid, the working fluid passes through the PTC and absorbs the solar energy. A part of the hot fluid then passes through the bottom of the PCM Tank and leaves from the topIn the PCM Tank, heat is absorbed by the PCM thereby cooling the working fluid.

The remaining hot fluid can be used for cooking during the day by passing it through the cooking unit. The working fluid leaving the cooking unit then meets that leaving the PCM Tank and the fluid is then pumped back through the PTC.

Fig 4.4 : Latent Heat Storage Solar Cooking Unit

c) Thermal Analysis of Lauric Acid

Thermal energy storage in domestic solar space heating and cooling application has been given attention since it can utilize this renewable energy to reduce the greenhouse gas emissions. It also provides a reservoir of energy to adjust the mismatch between peak and off peak time and meet the energy demand at all times. Thermal energy storage is basically classified as latent, sensible and chemical energy storage. The concept of using latent heat storage as energy saving vehicle provides the advantages of storing a large amount of energy in a small mass/volume and the phase transition occurring at nearly constant temperature.

In Phase Change Materials (PCMs), latent heat storage stores heat as latent heat of fusion during phase changes that undergo melting and solidification process. To gain a comfortable temperature in a space, the PCM can be employed to absorb heat when melting and release it when solidify. For a material to be used as PCM, some of the following criteria need to be fulfilled: high heat of fusion, high thermal conductivity, high density, and high specific heat, congruent melting, small volume changes during phase changes, chemical stability, and non corrosive, non poisonous, non flammable and non explosive. It is also noteworthy to take into consideration the availability as well as cost (Beghi, 1982).

The selection of PCM has recently been directed towards the use of low melting organic materials in an effort to avoid some of the problems inherent in inorganic phase change materials, such as super cooling and segregation. Special attention has been given to fatty acids since they can easily be obtained from renewable sources such as oils/fats (Feldman and Banu, 1996). Fatty acids show solid-liquid transitions within narrow temperature ranges. They possess some superior properties over other PCMs such as melting congruency, good chemical stability, non-toxicity and suitable melting temperature range for solar passive heating and cooling applications. In the liquid phases, these materials have surface tensions in the order of 20-30 dyne cm-1 and are therefore high enough to be retained in the structure of the host material. These materials possess elevated latent heat of transition and high specific heat (in the range 1.9-2.1 J g-1°C). They also exhibit only small volume changes during melting or solidification (example: melting dilatation is around 0.1-0.2 ml g-1). Because of the protected carboxyl group, fatty acids based PCMs are chemically, heat and colour stable, low corrosion activity and non-toxic.

PCM can be utilized as a single component or eutectic mixtures (binary mixtures that exhibit fixed melting/solidification points at a certain composition between two single components and act as single component).

d) Temperature Analysis of Lauric Acid

1) The temperature falls as the liquid cools. When the first crystals form, however, the temperature remains steady. As freezing takes place the temperature/time graph forms a plateau. After solidification is complete, the temperature drops quickly.
2) The initial, steep region involves the cooling of liquid. The average energy of the liquid molecules is lowered. During the horizontal portion of the curve, a phase change takes place. Solid forms as liquid freezes. Both the solid and liquid have the same average kinetic energy. The formation of bonds in the solid lattice requires the removal of energy (i.e., energy is released when these bonds form).
3) Once all of the liquid has frozen, the steep portion at the end of the curve involves reducing the average kinetic energy of the solid particles. The solid cools off.
4) The melting point of lauric acid 43 °C, so the material in the sample can be identified as lauric acid (not stearic acid, the other available choice). The material is liquid in the steep region at the left (early times) and solid in the steep region at the right (late times). Both liquid and solid coexist in the center, horizontal region.
5) Increasing the amount of unknown would not affect its melting point. (It would lengthen the plateau portion of the curve).
6) Energy absorbed by water = 150g x 4.2 J/g °C x 4.6 °C= 2.9x 10^3 J
7) DH (kJ/mol) = (2.9 x 10Ü kJ /17.98 g) x (204 g /mol = 3.3 x 10° J/mol
8) Increasing the amount of unknown would increase the amount of heat released to the water. It would not change the molar heat of fusion.

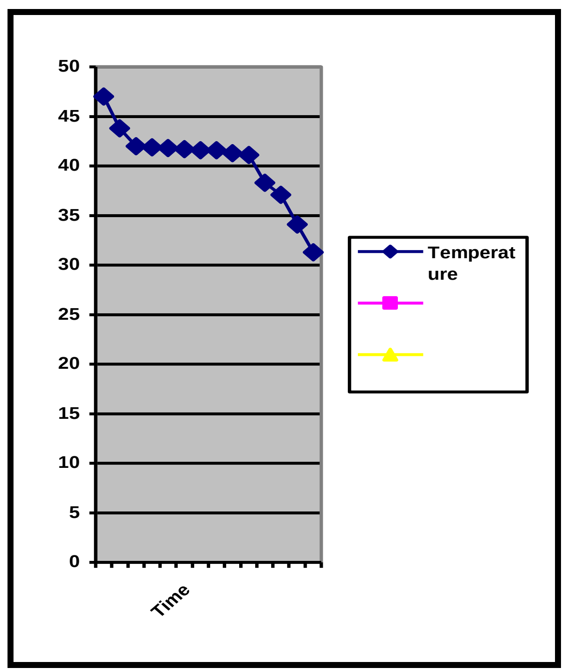


Fig 4.5 : temperature variation of Lauric acid

V. Performance Analysis

a) Average Energy Requirement For Cooking

- Calorific value of LPG = 45MJ/Kg
- Therefore, energy available in one cylinder (14.6kg) = 657MJ
- Assume a cylinder provides the energy for cooking for 35 days for a family of four.
- Energy requires to cook food for a family per day= 19MJ

b) Energy Received From Concentric Trough Collector

- Average solar insolation per day = 628.09 W/m²
- Energy received (8 hours of operation) = I × A = 628.09 × 1.07484 = 675.096 W
- Assuming the efficiency of the PTC to be 45%, net energy received = 303.793 W

c) Selection Of Pcm And Working Fluid

- After various studies, it was decided to use LAURIC ACID as the phase change material and SALINE WATER as the working fluid. LAURIC ACID was selected after analyzing its various properties. These were presented in the previous chapter. The thermal properties of SALINE WATER are provided. The thermal stability shown by SALINE WATER made it a suitable choice for the working fluid. The quantities required of each are calculated on the following page.

d) Total Mass Of Saline Water Required

- Specific heat capacity of saline water = 4.18 KJ/Kg/K
- Heat supplied to the saline water = 800.55KJ
- Hence total mass of saline water required = $m$saline water = 3.36Kg

e) Total Mass Of Lauric Acid Required

- Latent heat of fusion of Lauric acid = 182KJ/Kg
- Assume 30% of the heat is transferred from Saline water to Lauric acid = 240 KJ
- Heat supplied to Lauric acid = 240KJ
- Therefore, mass of Lauric acid required = 0.39Kg

f) Preliminary Test On Concentric Trough Collector

i. *Objective*

The objective of this analysis was to determine the maximum temperature attained by saline water and the temperature variation during the day of the working fluid under stagnant conditions in the Concentric Trough Collector.

ii. *Layout*

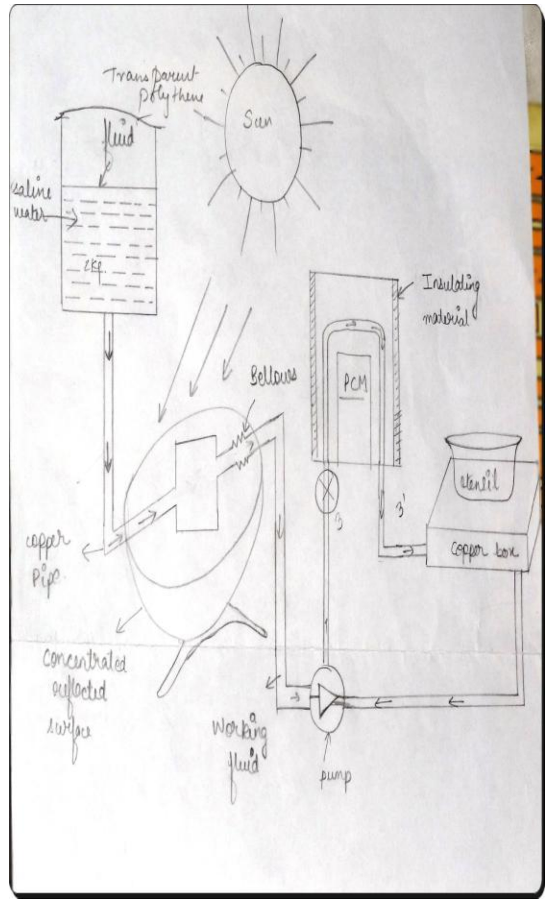


Figure 5.1 : The system shows the part of the experiment setup used for this analysis

- Thermometers were attached in either ends of the concentric collectors to measure the temperature of saline water residing in the concentric collector. T1 is taken as inlet temperature and T2 is taken as outlet temperature.

iii. *Readings*

Table 4.1 : Variation of T1 and T2 with time of day

Time of Day	T1 (inlet) (°C)	T2 (outlet) (°C)
10:00	28	28
10:30	29	45
11:00	31	56
11:30	32	66
12:00	33	75
12:30	35	82
1:00	37	87
1:30	38	92
2:00	38	95
2:30	38	94
3:00	38	87
3:30	38	82
4:00	37	78
4:30	35	75
5:00	34	72

5:30	33	68
6:00	33	66
6:30	32	64
7:00	31	62

iv. *Graph*

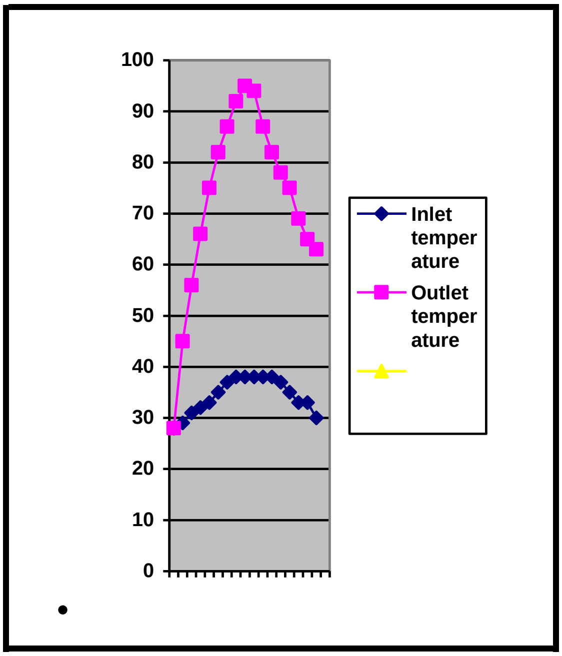


Figure 5.2 : Variation of T1 and T2 with time of day

v. *Observation and Inference*

- Maximum temperature achieved by Saline water = 95°C. From this it can be inferred that even while accounting for losses, the temperature attained by the Saline water by passing it through the CTC will be sufficient to heat the Lauric acid up to its melting point of around 42°C.

g) Modification of The Ctc

The performance analysis shown above corresponds to the CTC having a focal length of 16.411 cm. Before conducting the above analysis, the focal length of the PTC was 8 cm. With that focal length, the maximum temperature attained by saline water was found to be only 85°C as opposed to the 95°C obtained above. The calculations done below show that 16.411 cm is very nearly the optimum focal length of the CTC used in this project.

- It is known that the diameter of the PTC is 98 cm and the depth is 36.575 cm. The focal length can then be calculated using the formula (4.1) on the following page.
- If f= focal length, D= diameter and c= height of the CTC, then we have,
- $f= D^2/16c$ (4.1)
- Substituting the known values, we get, f = 16.411cm.

Figure 5.3 on the following page shows the various parameters used to ascertain the focal length of the PTC.

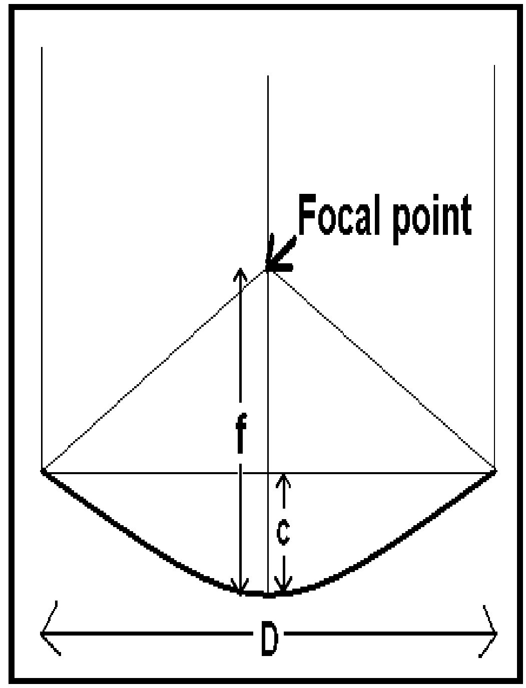


Figure 5.3 : This schematic shows the various parameters of the CTC

c and *D* were used to determine *f* as shown above Consequently, increasing the focal length resulted in better CTC performance as evidenced by the result of the performance analysis of the CTC.

VI. Results and Discussion

The performance of the concentric trough collector and the phase change material were analyzed after performing the experiment. This chapter explains how the experiment was conducted followed by the results obtained. The results are then interpreted, thus leading to the conclusion.

a) Methodology

The experiment was conducted over a period of three days. On the first day, the Saline water was heated using the concentric trough collector. The heat transferred to the Saline water was then passed on to the Lauric acid in the charging process. The experiment started at 10:000 a.m. and continued till 7:00 p.m. The temperature of the Saline water increased from 28°C to 95°C. This saw the close of experimentation on day 1.

Day 2, on day 1 the Saline water temperature recorded 95°C. Following this, the discharging of the Lauric acid and the drop in temperature of Saline water was observed and a water boiling test was conducted on the flat plate cooking unit.

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b) PCM Tank Heat Loss Co-Efficient

Before conducting the charging and discharging experiments, it was essential to determine the heat loss co-efficient of the insulated PCM tank, insulated placing it in a thermocol box of 15mm thickness. During the experiment, the temperature of saline water was heated to 95°C. The total time during which the heat loss was observed was 9 hours. The graph of Temperature drop versus time is shown in figure 5.1. The temperature drop values recorded are shown in table 5.1.

At the start, the temperature of the saline water was 95°C and after 9 hours, it was found to be 62°C. Thus the temperature loss was obtained as

Rate of temperature drop = (95-62)/9 = 3.666°C/h

Table 6.3 : Variation of temperature drop of Saline water with time

Time(hours)	Temperature (°C)
1	95
2	94
3	87
4	82
5	78
6	75
7	72
8	68
9	66

c) Graph

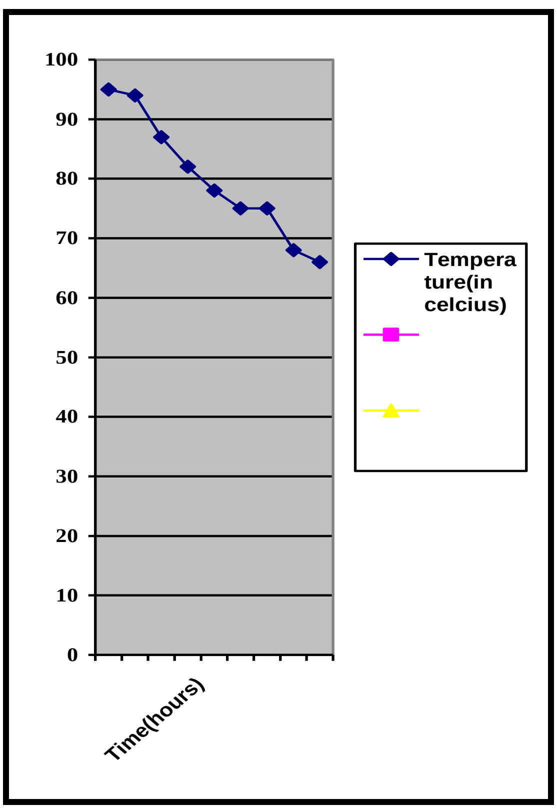

Figure 5.4 : Variation of temperature drop of Saline water with time

The total amount of working fluid in the experimental setup is 18 kg. Assuming that 30% is located in the pipes, amount of working fluid in the PCM tank will be 1.5 kg. Hence, Energy lost from Saline water in 9 hours = 18 × 4.18× (95-66) = 2181.96 KJ

The mass of Lauric acid used in the PCM tank was 1.5 kg. Hence, Energy lost from Saline water in 9 hours = 1.5× 2.4 × (95-66) = 104.4KJ

From this we have,

$U \times A \times LMTD$ = [(2181.96 + 104.4) × 1000] / (9 × 3600) = 70.56W

However, assuming ambient temperature to be 28°C,

$LMTD$= (95-66) / ln (95/66) = 79.62°C

∴ U = 70.56/ (πdl × 79.62) = 8.983 W/m² K

d) Charging Process

The charging process of the experiment was conducted in one day. One that day charging was done using the energy obtained from the CTC.

i. *Day 1*

Table 5.2 on the following page shows the temperature of Saline water at different times of the day during the charging process. Figure 5.2 shows the corresponding graph.

Time (in Celsius)	Temperature
10:00 am	28
10:30 am	45
11:00 am	56
11:30 am	66
12:00 pm	75
12:30 pm	82
1:00 pm	87
1:30 pm	92
2:00 pm	94
2:30 pm	95

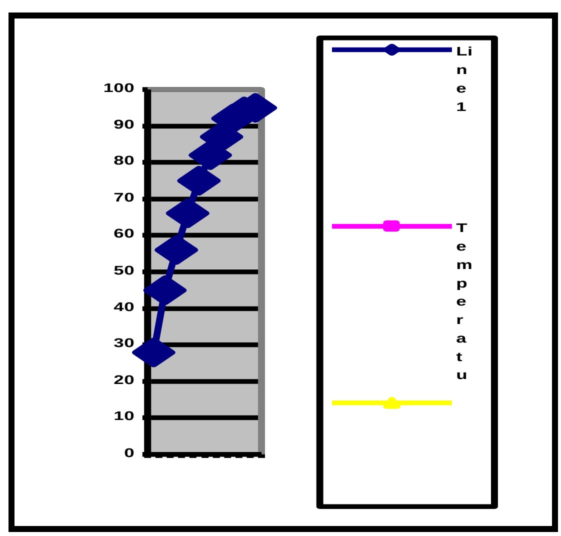

Figure 5.5 : Variation of temperature of Saline water

e) Water Boiling Test

The water boiling test was conducted to determine whether or not the heat generated at the cooking unit was sufficient to boil water during the discharging process. It was conducted by keeping a vessel with half liters of water at room temperature on the flat plate cooking unit. The temperature of the water mass was monitored at regular intervals. Fig 5.3 shows the cooking unit plate temperature and water temperature as a function of time. It is observed from the figure that the water temperature reaches 85°C after 4.5hours.

Table 5.3 : Water boiling test

Time (in minutes)	Water Temperature	Plate Temperature
0	28	27
30	37	34.5
60	46.5	41.5
90	54.5	48.5
120	61.7	55.3
150	68.7	61.7
180	75.6	68.3
210	87	74.9
270	92	80.8
300	95	86.5

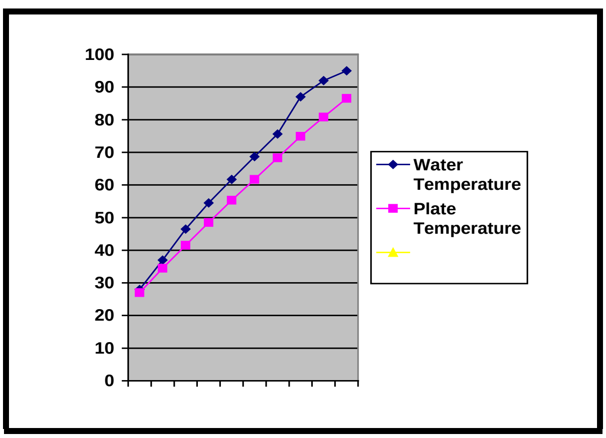

Figure 5.6 : Cooking unit plate temperature and water temperature versus time

VII. Advantages, Limitations & Applications

a) Advantages

The advantages of the night cooking solar cooker can be summed up as below:

1. Cooking beyond sunshine hours.
2. Indoor cooking facility.
3. Ease of availability of component materials and cost effectiveness of the same.
4. Eco-friendly and no health hazards on the user.
5. The water condensed, provides a source of clean drinking water or can be reused.

Within the given constraints, making a solar cooker that too with traditional means is no easy task. This design though may face greater practical difficulties when enacted but it will be robust enough in principle. Even if it's not a complete solution to the problem of Energy efficiency but the design does add to this cause.

b) Limitations

The limitations of night cooking solar cooker can be summed up as below:

1. Set up is costly.
2. Unavailability of the Phase Change Material.
3. Depends upon the weather conditions.

c) Applications

Following are the various applications of night cooking solar cooker:

A. Number of other applications besides cooking, such as process heating and so on.
B. The lauric acid used as the Phase Change Material is also used as excipient and diluents for solids and liquids in pharmaceuticals.
C. In making artificial resins and plasticizers.
D. In analytical chemistry for boron determinations.

VIII. Conclusion

An exhaustive literature survey was done on the various applications of PCMs. Storage of thermal energy using PCM was studied. The PCM tank was then designed as per the energy requirement to cook for an average family. The experimental setup was then completed by using various valves, nipples, hoses, T-joints etc. The temperature drop from the system was calculated. The charging and discharging characteristics of the PCM was studied in detail.

From the results obtained by the experiment, we were able to conclude that the parabolic trough collector was able to deliver Saline water at a high temperature. The heat passed on to the PCM from the Saline water was sufficient to melt the PCM thereby enabling latent heat storage. This process was called the charging process. In the discharging process, the heat released by the PCM to the Saline water was found to be sufficient to boil water as evidenced by the results of the water boiling test.

In order to improve the performance of the system, a phase change material having a higher heat capacity and melting point can be used. Additionally, based on the cooking range being used, the design of the cooking units can be modified. Moreover, this idea can be extended for use in a number of other applications besides cooking, such as process heating and so on. In a way this Latest Heat Storage System acts as Panacea to Address, to some extent, Energy Needs of a country like India.

IX. Future Scope

Presently, cooking at night is achieved primarily by burning fuels such as LPG or, in some cases, by utilizing electricity to run, say, a microwave oven. However, LPG is not renewable and its cost is likely to increase as time goes by. Looking at alternative sources of fuel, solar energy might be a plausible solution. The success of this project implies that although solar energy is effectively available for about eight hours at a given place, the same can be utilized throughout the day and partly at night. On the long run, it will be relatively inexpensive when compared to conventional energy sources, it will not pose a threat to the environment or cause its deterioration in any way and its availability will not be a concern to mankind. The scope is positive.

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