Investigation of Phase Change Material Based On Thermal Storage System for Crop Dryer Using Solar Energy

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Abstract:
Commercial dried eatable things like vegetable foods with high quality of dried under the conditions. Food substances require controlled drying environment, in order to retain it’s natural parameters. In traditional drying method, the food substances spreading under the sun where the drying time so long as well as the product affected by the external condition’s, this method leads to losses of quality and it’s price. Instead of this we have an idea to apply modern technology which as “SOLAR DRYING METHOD” to obtain good quality in efficient manner. This proposed work involves the design & construction of solar cabinet dryers using phase change material to store the thermal energy. Tests were taken under natural and forced convection in the form of normal and honeycomb arrangements 0f PCM.

Keywords: solar air heater, drying chamber, thermal energy storage, phase change material, natural convection, forced convection.

1. Introduction
In the recent years, most of development countries around the world were facing the problem of energy crisis because of the large gap between demand and supply of energy. This problem can be minimized to some extent by utilizing renewable energy sources. Solar is available in large quantities in the world.

Solar air collectors are simple, cheap and most widely used. It used mostly for space heating, solar desalinations, solar water heater, industrial process heat and also for drying. Solar energy includes systems of drying is very attractive application and cost competitive such as drying of cocoa, coffee beans, fruits, noodles, rubber, or marine products.

Sarviya, et al[1] studied experimental investigation of shell and tube LHTS for solar dryer using paraffin wax as the heat storage material. A thermal and Heat transfer characteristics of LHTS and heat transfer fluid has been studied to analysis the heat transfer during charging and discharging process. The radial and longitudinal direction of different time during charging process to analyze the heat transfer phenomena in the LHTS. Results show that the hot air of drying food products in non sun shine hours is suitable only by LHS. During the discharging of LHTS the temperature gain is around 17°C to 5°C.

Shalby and Bek[2] conducted an experiment on indirect solar dryer using phase change material as storage material on Nerium oleander. The prescribed drying temperature of nerium oleander is 50+/-2.5°C. 12 Kg of paraffin wax was used as latent heat storage. T was observed that thermal storage medium maintains the temperature of drying air around 50˚ for 7 consecutive hours. Also temperature of drying air is greater than the ambient temperature by 2.5 to 5˚ C after sunset for 5 hours at least.

Krishnanath, et al [3] conducted an experimental study on a double pass solar air heater with TES. In this TES is integrated and fabricated in double pass air heater in which paraffin wax was used as storage medium. The efficiency of the integrated TES is higher than the air heater without TES.

Ahmad et al [5] analysis the double pass solar performance in absorber plate which involves the investigation of effect of mass flow rate number and height orphans with steady state energy balance equation in Solar collectors and result shows that there is an collector efficiency increase in number and height of twins. The result was given that the collector has increase in flow rate and high efficiency.

Preeti, et al [6], conducted experiment on natural convection type solar dryer with latent heat storage by taking ginger as drying material and paraffin wax as phase change material. The set up was made such that the collector area was 2 sq. m, drying chamber of 0.8 m2 and storage volume of 0.0060 m3. During no load test, maximum temperature attained in collector and drying chamber was 102°C and 61˚C respectively for peak radiation of 870 W/m2. It was observed that the ginger dryer from 74% to 3% in 24 hours. Average efficiency was found between 53% and 96% while having a backup period of 2 hours of storage material.

Mahmud, et al [7] conducted an experimental study of fabrication of PCM capsules integrated in solar air heaters. Two capsules were tested for storage medium using pure paraffin wax of 70µm and paraffin wax-aluminum composite. The main
focus was given on discharge process. Two cases were tested for storage medium used the above said composition. It was observed that the charging time was reduced by approximately 70% were the paraffin wax – aluminum composite. The thermal storage efficiency reached maximum magnitudes of 71.9 and 77.8 % respectively, thus proving more advantageous by adding aluminum composites.

2. Summary of literature review

The study made from above literatures, a broad idea of advanced solar air drying techniques that can be utilized for crop drying. A wide perspective of PCM based thermal energy storage, that can be integrated with solar dryer to improve the efficiency of the system is studied that will be vital in proceeding this work.

3. Problem identification and Methodology

In traditional drying method, the food substance spending under the sun where the drying time so long as well as the product affected by the external conditions, this method leads to losses and quality and its price. Instead of this we have an idea to apply modern technology which as “SOLAR DRYING METHOD” to obtain good quality in efficient manner. Aluminium is used as the solar heat collecting material. The aluminium material was coated with black paint as to ensure the entrapping of solar energy. Paraffin wax is used as the thermal energy storage material, glass is used for covering the air heater from the top. The potato is taken as the drying product and 1000 grms of potatoes is equally divided into three trays in drying cabinet. There is also provision for measuring the quantity of air entering into the apparatus and to measure the temperatures at various sections of the apparatus.

4. Description of the equipments

4.1 Solar air heater

The heat absorber (inner box) of the solar air heater was constructed using 1mm thick aluminum plate which is coated with black paint as absorber coating. The solar air heater assembly consists of air flow channel enclosed by transparent glass of thickness of 4mm. Copper is known to have high thermal conductivity(386W/mK) but due to its high cost, next to copper stands aluminium with a better thermal conductivity(249W/Mk). So we choose a absorber plate as aluminium material according to the requirements.

![Figure 4.1 solar air heater](image)

<table>
<thead>
<tr>
<th>Area of collector, (A_c(\text{m}^2))</th>
<th>1 (\text{m}^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of glass covers, (N)</td>
<td>1</td>
</tr>
<tr>
<td>Transmissivity ((\tau))</td>
<td>0.85</td>
</tr>
<tr>
<td>Absorptivity ((\alpha))</td>
<td>0.96</td>
</tr>
<tr>
<td>Absorber plate thickness, (\delta)</td>
<td>1 (\text{mm})</td>
</tr>
<tr>
<td>Thermal conductivity of aluminium</td>
<td>249 W/m K</td>
</tr>
<tr>
<td>plate</td>
<td></td>
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</tbody>
</table>

4.2 Drying Cabinet

The drying cabinet is completely made up of different types of material. The insulation material is thermocol of 30mm thickness which will reduce the heat losses. Insulating material is covered with two types of materials. The internal material is aluminum plate of 1mm thickness and the external material is wood with 12mm thickness. Three stainless trays are used in the drying cabinet to hold drying products, this tray is placed at the distance of 100mm between each trays.
4.3 Drying Trays

The drying trays are kept inside the drying chamber for holding of grain samples, and were constructed from a wood, aluminum material, with stainless steel mesh with a fairly open structure to allow drying air to pass through the sample items and to reduce the corrosion.

4.4 Storage System

Thermal storage is the process of storing the heat energy when available in excess. This thermal storage is used to maintain the temperature of exit air when the sunshine in not at peak, this is made possible by the use of phase change material. Paraffin wax is used as a PCM in this project. The storage units consist of paraffin wax filled in the aluminium coated covers and which is placed in the absorber plate. And these aluminium coated covers are placed in the drying chamber in non sun shine hours.

4.5 Blower

Blower is used for blowing air at a required velocity to the air collector. The velocity of air at their inlet of the solar air collector can be controlled

5. Fabrication process

By performing various machining processes, every parts of the air heater are fabricated based on the design and dimensions.

6. Experimental setup

The experimental setup consists of two major components- solar dryers and solar air heater. The former is composed of components like insulation material, absorber plate, glass and coating material. The absorber plate is made up of aluminium with thickness of 1mm and the area of 1m² * 1m² which is used for absorbing solar energy the alternative material that can be used for absorber plate is copper which as the high heat capacity than aluminium in absorbing solar energy which can be used in real time system. The insulating material that is used in the proposed model is foam with the thickness of 50mm which is used to reduce the heat losses. The important material that used in the experiment is glass with thickness of 4mm. the solar air heater consist of inlet 25 mm diameter and 10 outlets of 25mm diameter. The coating material used in the absorber plate is black paint to absorb solar energy more efficiently.

The latter is designed by taking width of 540mm and height of 700mm in one side and 800mm in other side which consist of 3 drying trays which is made of stainless steel material which is placed 100mm difference to each other. And PCM tray is being used of which has the gap of 200mm and the materials like aluminium and foam of 1mm and 20mm thickness used inside the drying chamber.

Two sets of tests were conducted, with and without drying products, the no load test was a preliminary test with no PCM integrated in it. Full load test is taken such that PCM was arranged in two ways- normal arrangement and honeycomb arrangements.
### 7. MATHEMATICAL CALCULATIONS

#### Calculations of natural convection:

Drying characteristics of solar dryer in natural convection using normal and honeycomb arrangement.

1) Amount of water content in product, $M_{tw}$

$$M_{tw} = \frac{W_g * (M_i)}{100} \quad (7.1)$$

Where,
- $W_g$ = material weight
- $M_i$ = moisture content present in product initially.

2) Completely dried weight of material, $W_{cdw}$

$$W_{cdw} = W_g * (1 - \frac{M_i}{100}) \quad (7.2)$$

Where,
- $W_{cdw}$ = complete dried weight (kg)

3) Water removed while drying, $M_w$ kg

$$M_w = [(m_i - m_f/100 - m_f)] * W \quad (7.3)$$

Where,
- $m_i$ = moisture content after drying, %
- $m_f$ = moisture content before drying, %
- $W$ = product’s mass, Kg

4) Amount of water removed per hour $m_w$, Kg/h

$$m_w = \frac{M_w}{T_d} \quad (7.4)$$

Where,
- $m_w$ = mass of water to be removed during drying, Kg
- $T_d$ = assumed drying time, hr
- $M_w$ = mass of water to be removed by drying, Kg
- $C_w$ = specific heat of water, kJ/kg°C
- $l$ = Latent heat of vaporization, kJ/kg

5) Total energy required, $Q$ (KJ)

$$Q = \left( C_{DW} * C_{p} * (T_f - T_a) \right) + \left( M_{tw} * C_{w} * (T_f - T_a) \right) + (M_w * l) \quad (7.5)$$

Where,
- $CDW$ = complete dried weight of moisture, Kg
- $C_p$ = specific heat of wet product, kJ/Kg°C
- $T_f$ = final temperature, °C
- $T_a$ = ambient temperature, °C
- $C_w$ = specific heat of water, kJ/kg°C
- $l$ = Latent heat of vaporization, kJ/kg

6) The energy required per hour, $Q_\text{c}$, kJ/hr

$$Q_\text{c} = \frac{Q}{T_d} \quad (7.6)$$

Where,
- $Q$ = total energy required, kJ
- $T_d$ = assumed drying time, hr

7) Area of collector, $A_c$

$$A_c = \frac{Q_\text{c} * 100}{I * h} \quad (7.7)$$

Where,
- $h$ = efficiency of collector

#### Calculation of forced convection:

Velocity of air coming out of blower is found out by anemometer.

1) Velocity, $c$= 4.1 m/s (0.047kg/s)

2) Atmospheric pressure of air, $P$=1.013*10$^5$ Pa

3) The mass flow rate of air entering the blower is given by

$$M = r * A_c \quad (7.8)$$

Where,
- $r$ = density kg/m$^3$
- $A$ = diameter of blower, cm$^2$

4) Density, kg/m$^3$

$$r = \frac{P}{R * T} \quad (7.9)$$

Where,
- $R$ = gas constant
- $T$ = ambient temperature, °C

5) Heat transfer, Watts

$$Q = m * C_p * DT \quad (7.10)$$

6) Efficiency,

$$h = \frac{Q}{I * A} \quad (7.11)$$

Where,
- $A$ = Area of collector, m$^2$
8. RESULTS AND DISCUSSION

The experiments were conducted and the results pertaining to it were obtained. The following are the results for various tests conducted.

Figure 8.1 Characteristic curve of natural convection in normal arrangement

It can be seen from the figure 6.9, the inlet temperature, outlet temperature, glass temperature, plate temperature, ambient temperature and the radiation level are calibrated from 9:30 am to 4:00pm at the interval of 30 minutes. In the normal arrangement of phase change material, the plate temperature is around 60°C and outlet temperature is around 52°C. The fluctuation of temperature is reduced due to the normal arrangement of phase change material.

Figure 8.2. Characteristic curve of forced convection in normal arrangement

It can be seen from the figure 6.11, the inlet temperature, outlet temperature, glass temperature, plate temperature, ambient and outlet temperature is around 54°C. The fluctuation of temperature and the radiation level are calibrated from 9:30 am to temperature is reduced due to the normal arrangement of phase 4:00pm at the interval of 30 minutes. In the normal arrangement change material.
It can be seen from the figure 6.13, the inlet temperature, outlet temperature, glass temperature, plate temperature, ambient temperature and the radiation level are calibrated from 9:30 am to 4:00pm at the interval of 30 minutes. In the honeycomb arrangement of phase change material, the plate temperature is around 59°C and outlet temperature is around 52°C. The fluctuation of temperature is reduced due to the honeycomb arrangement of phase change material.

Figure 8.3 Characteristic curve of natural convection in honeycomb arrangement

Figure 8.4. Characteristic curve of forced convection in honeycomb arrangement
It can be seen from the figure 6.15, the inlet temperature, outlet temperature, glass temperature, plate temperature, ambient temperature and the radiation level are calibrated from 9:30 am to 4:00pm at the interval of 30 minutes. In the honeycomb arrangement of phase change material, the plate temperature is around 61°C and outlet temperature is around 54°C. The fluctuation of temperature is reduced due to the honeycomb arrangement of phase change material.

![Figure 6.15. Efficiency VS time curve (Normal and honeycomb arrangement)](image)

**Figure 8.5. Efficiency VS time curve (Normal and honeycomb arrangement)**

In the above Figure 6.31, natural convection and forced convection normal and honeycomb arrangement has been calibrated. In normal arrangement, the efficiency of natural and forced convection are 46.07% and 48.4% and in honeycomb arrangement the efficiency of natural and forced convection are 55.0 % and 68.93% respectively.

**Comparison of efficiency**

**Normal and honeycomb arrangement**

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<tbody>
<tr>
<td>Natural convection – Normal arrangement</td>
<td>46.07 %</td>
<td></td>
</tr>
<tr>
<td>Forced convection – normal arrangement</td>
<td>48.4 %</td>
<td></td>
</tr>
<tr>
<td>Natural convection – honeycomb arrangement</td>
<td>55.02 %</td>
<td></td>
</tr>
<tr>
<td>Forced convection – honeycomb arrangement</td>
<td>68.93 %</td>
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From the above table, it is very clear that the honeycomb arrangement of phase change material as better efficiency than the normal arrangement of phase change material.

9. **Conclusion**

Thus by following all the design procedures the solar crop dryer was designed and fabricated. The results on every aspect of the solar dryer were portrayed. Natural and forced convection was taken on drying chamber by arranging the paraffin wax packed in aluminium sheets on both normal and honeycomb type arrangement. the efficiency of forced convection by arranging the packets in honeycomb type is much higher, about 68.93%, compared to the conventional arrangement. Hence this solar dryer can be used for agriculture purposes.

**FUTURE SCOPE OF THE WORK**

In this work, products were dried during sunshine and non-sunshine hours with different types of PCM arrangement. Here aluminum was used as absorber plate, with black board coatings, producing an efficiency of 68.93%. at peak time. However, to obtain more efficiency, the experimentation can be carried out by taking copper as absorber plate material, with black chrome coatings since it has high absorptivity and less reflectivity than black board paint. Various PCM materials like silica gel, etc. can be used.
References


