Performance and Investigation on a Solar Dryer with Thermal Storage

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Abstract: An indirect type solar dryer combined with a charcoal burning stove that may be used for drying fruits was developed, built and assessed. The research primarily attempted to solve the issue connected with the fact that solar dryers are effectively operational only when there is adequate sun energy. Hence, an extra method of providing heat was added so that drying may be made continuous throughout the night time and in rainy seasons. Solar food processing is the effective and affordable option for addressing various food issues in the postharvest stage and also to the world’s energy needs. Solar dryer appears to be a very helpful equipment in the point of view of energy saving and environmental pollution. It saves quite a lot of energy or fossil fuel and also beneficial in the areas of quality of dried goods, space need, and capital cost. An indirect forced convection sun dryer combined with packed bed sensible heat storage medium was created and investigated at the climatic conditions of Chennai, India. The experimental equipment comprises of a blower, solar flat plate collector with corrugated absorber plate (2 m²) and a drying chamber. For the construction of solar collector, drying chamber and connecting ducts, Galvanized Iron sheet was chosen and pebbles opted for the porous thermal storage medium.

Keywords: Solar food, energy, Solar dryer, solar flat, Thermal Storage

1. INTRODUCTION

Food is the most important item to live for people. As the world's population is growing, the demand for food is extremely difficult for everyone to meet. Food losses may thus be prevented. The ancient method prevents food from being damaged by drying. The drying process uses sun energy naturally. For safe drying, i.e. for drying, food items especially fruit and vegetables need hot air in the temperature range of 45 – 60 °C to keep their edible and nutritional qualities intact. The required moisture content and better product quality may be obtained under regulated temperature and humidity conditions. Solar dryers may decrease crop loss and substantially enhance product quality compared to conventional drying techniques, such as sun/shade drying. The food loss happens in poor nations owing to many causes, for example inappropriate planting and fertilisation, lack of adequate technologies, incorrect transport, lack of marketing channels, heavy post-harvest losses, etc. Food loss is due to above mentioned causes from 10 to 40 percent of overall output. Food preservation is the sole method for reducing food losses after harvest. In preserving agricultural goods, drying is an important step. For safe drying, food items, particularly fruits and vegetables, need hot air at a temperature of 45-60 °C. Drying under regulated temperature and humidity conditions helps agricultural food items dry fairly quickly to guarantee safe moisture content and improved product quality. Mostly in industrial drying operations, controlled drying is performed. Hot air for industrial drying is often supplied by combustion of fossil fuels and huge amounts of fuels are utilized for that purpose globally. High prices of fossil fuels, progressive depletion of their reserves, and environmental effects have placed significant restrictions on use. Many rural areas of developing nations are affected by the failure to access grid power; the supply of alternative non-renewable energy sources is either unavailable or unreliable or too costly for many farmers. In such locations, crop drying methods that use fans, heaters and other accessories electrically powered are not suitable. The high cost of capital and operating fossil-fuel dryers for small farmers are frequently not cheap India's wonderful sunlight is fortunate. Most regions of the nation get average daily solar radiation of 5-7 kWh m², and over 275 bright days per year. Solar drying thus has a strong dissemination potential in the country and provides options accessible in the home sector. It offers several benefits such as no recurrent expenses, the possibility to decrease drudgery, a high food nutritious content, a high resilience, and so on. However, the major difficulties in disseminating it are unwillingness to embrace new technology, intermittent sunlight nature, limited availability of space in metropolitan areas, greater initial prices and convenience problems. Solar energy is free, clean and is thus regarded as one of the most promising alternative energy solutions choices. In the near future, we may look forward to the large-scale deployment of solar power systems which convert solar radiation directly into heat. However, by its nature, solar power is intermittent; no sun at night. Its entire available value is seasonal and depends on the location's weather. Unreliability is the major delay
factor for widespread use of solar energy. Of course. Of course. The reliability of solar energy may be improved if it is overloaded and if required, it can be stored with the stored energy. Therefore, energy storage is necessary for any system that is primarily dependent on solar energy. It balances time differences between the load and the intermittent or variable supply of energy, increasing system functionality and utility. Solar radiation cannot be stored as such, therefore first a conversion of power must be carried out and a storage device is required based on this conversion. Thermal, electric, chemical and mechanical techniques may be used to store solar energy.

Solar energy is one of the largest sources of renewable energy and is known as energy from sunlight. Solar energy may be used in various ways, such as heating homes, power supply, distillation of sea water. Energy is a type of solar energy utilised for many different activities. One of the major uses is the many applications of sun drying. Solar dryers are used to capture solar energy from air collectors. The aim of sun drying is to reduce the moisture content of goods to a level that may avoid their deterioration. The first is heat transfer to the product utilising heat energy and mass transfer of moisture from inside the product to its surface. The second is from the surface to the surrounding air. The second is the process of drying, drying. The farmers traditionally utilise open drying techniques that utilise sun radiation intensity, air ambient temperature, ambient air humidity and wind speed. In this technique, food and perishable goods are put directly on the floors, which may achieve temperatures greater than during open-drying and dry for many days. The aim of a sun dryer is to provide the product with hotter air than naturally accessible air and to reduce the relative humidity of air. There are two kinds of solar dryers: first, the sun energy is the sole source of heat, i.e. direct mode, and the second, which utilises solar energy to heat air and transport air to goods. The airflow in the dryer may be conveyed naturally or pushed by a blower convection. In dryers, the products may be exposed to sun radiation directly for drying or utilising the dryer or a combination of the two. In the dryer the product is heated directly by the air flowing through the product. Transfer of heat from the air to the food items is carried by forced convection to the product by direct radiation from the open drying and by conduction from heated surfaces of a product in contact with the product at a higher temperature than that of the product.

II. LITERATURE REVIEW

Vikramjose.L (2018) The use of natural energy resources is solar dryer. The materials used in thermal energy storage utilised in these solar dryers are used in the sunlight to store energy and are used in off-sunshine. Temperature range in constant condition for continuous drying of agricultural and culinary goods. Thermal energy storage needs solar dryers for continual drying processes and improves system efficiency. This article examines the recent development of a mixed-mode solar dryer based on several thermal energy storage systems. And they also examined solar dryer methods and their effectiveness in relation to other solar dryer techniques using the thermal energy storage system.

Vaibhav. V. (2016) Drying is a key technique for preserving agricultural food items. Products, in particular fruits, need hot air for safe drying in the temperature range 45-600C. In this, the small and portable convection solar drier for drying chilies with thermal energy storage have been developed. The solar dryer performance has been experimentally evaluated. The solar dryer is 15 kg of perishable foodstuffs and consists of the heating system based on flat panels and thermal energy storage, utilised as a material to alter the phase by Paraffin wax (PCM). The effects of mass air flow rates on the collector’s temperature, the dryer chamber, the drying rate and drying time with and without thermal energy system installation were investigated. The solar collector and solar dryer efficiency has been estimated. Result indicates that drying of chilies in contrast with the literature is technically possible, including humidity and a decrease in the drying time. The drying chamber temperature was observed 6-9 0 C higher than after hours of sunlight the ambient temperature for up to 6-7 hours. The drying period for the chilies with thermal energy storage was determined to be 17 hours. In this current study, testing and experimentation in various situations has been done out: 1) The air mass flow rate ranges between 0.006, 0.008 and 0.01 kg/s. 2) Materials with and without phase transition.

P.M Diaz (2016) Dangerous gas emissions from many domains have been a topic of concern in many nations. CO2 is such a harmful gas that requires a great deal of attention. It may have dangerous environmental consequences if left uncontrolled. There have been several recent measures to slash these emissions. Renewable energy sources and energy efficiency are the two areas of the researchers’ interest in addressing these issues. In this paper, the focus is on technology for thermal energy storage (TES). Thermal energy collected by heating or cooling a storage medium is stored by TES. This energy can be used in heating, cooling and power generation systems later. Environmental risks may be avoided, peak demand and energy use decreased, more efficient and cost-effective systems enabled. Through such thermal energy storage, the proportion of renewable energy may be enhanced. Similar to other technologies, TES also has some obstacles to their market entry. The main factors to be addressed are performance and cost. Extensive study and analysis are needed for the effective deployment of TES. This paper focuses primarily on the principles, evaluation and comparison of TES and their varieties. Advances are also addressed in this area.
Hii et al. (2012) Sun drying (laying of plants in direct sunlight) has proven to be cheap but the result produced is of poorer quality due to pollution by dust, insects, birds, animals and plants. Loss of vitamins, nutrients and undesirable colour changes as a result of direct contact to UV radiation and long-term dryness are also necessary.


Mohapatra et al. (2013) The natural convection grain drier was designed to dry rice and other grains efficiently using the thermal energy. Paddy's typical drying temperature ranges from 50°C to 58°C. The drying efficiency of the system is calculated at 50.4 per cent for drying 100 kg of paddy. A 20 kilogramme GradeII paraffin wax was utilised as a phase transition material for a consistent drying rate. The product's moisture content is decreased from 30.1% to 14.6%.

Raju et al. (2013) Designed and manufactured a cabinet style direct sun dryer. In two days, it was used to dry 20 kg of fresh veggies like chilli and tomato. The dryer was built in India and an experimental drying test was performed on a prototype of the dryer with a solar collector area of 1.03 m². The dryer is 100x103x76 cm³ in size and has a sidewalls of 32 galvanised steel and a wood floor. A glass is utilised as a cover and an air circulation hole of 5 cm has been created. The optimum solar dryer temperature was intended to be 60°C with a 30°C ambient temperature or air intake temperature. At the conclusion of the first day of drying using this drier, the weight of the product was reduced to 1180 grammes, while the same weight was reduced to 1550 grammes when dried by the open sun. The ultimate potato weight was decreased by the drier to 550 grammes on the second day, while it was reduced by open sun drying to 920 grammes.

Svenneling (2012) designed and tested an indirect solar dryer for drying pineapples in Ghana. The solar collector had an area of 1.05 m² and the air duct had a gap of 0.2 m. A 1.2 m long chimney with a diameter of 0.1 m was made from metal sheet and is connected to the drying chamber. Laboratory drying test of pineapples showed that the slices had become case hardened when dried at 70°C for five hours. But when dried at 50°C, it took about 23.43 hours for the pineapple pieces to reach a moisture content of 10%. At this point, the pieces had become light yellow and pale 33 and were ready to consume. The longer drying period in the laboratory was attributed to inadequate ventilation in the oven. When using the solar dryer at the test location, the temperature in the collector and the drying chamber reached approximately 60°C and 50°C respectively. The moisture content was reduced from 90% on the wet basis to about 10% within 16 sunshine hours. It was also shown that the drying rate was faster on the lower shelf that is closer to the collector than the upper shelf. It was indicated that, due to high humidity in Ghana, some of the tools used to construct the dryer started to corrode after only a short period of time which affected the modification of dryer. The large size of the dryer had also made it difficult for handling while moving it from one place to another.

### III. DESIGN PROCEDURE

The design of the solar dryer has taken many design requirements and factors into account. Some of the design criteria and characteristics have been derived through literature research while others have been established via a series of mathematical calculations. These design factors comprised ambient variables at the test site, drying temperature, moisture quantity to be removed, heat energy consumption and airflow requirement calculation.

The dryer performance has been assessed at Kumasi (6°42'N latitude and 1°57’W longitude) (Moujaled, 2014). The average solar radiation for Kumasi was approximately 340.8 W/m² according to observations by the Meteorological Services Department of Ghana and Kwame Nkrumah University of Science and Technology. Ta, the environmental temperature at the test site was 25°C (Forson et al., 2007 and Ansi, 2007), with a relative moisture content of 70%.

#### 3.1 Drying Temperature

Scanlin (1997) suggested drying temperatures between 37.7-54.4°C for fruits and vegetables. Increased temperatures may cause a large number of fruit items to caramelize sugar (browning sugar) while drying. The average drying temperature, Td, of 45°C, was thus considered for drier design.

#### 3.2 Amount of Moisture to be Removed

Bassey and Schmidt (1987) provide a method for calculating the total moisture to be removed (Mw):

\[ M_w = \frac{W_w (M_i - M_r)}{1 - M_r} \]  

(3.1)

where:

- \( M_w = \) amount of moisture removed
- \( W_w = \) initial total weight;
Mi = initial moisture content on wet basis;
Mf = the final moisture content on wet basis;
The drying area is determined by the quantity to be dried, and because the dryer has three trays and has been designed for the experimental purpose, an initial 3 kg should be considered for the dryer design. Thus, pineapples would dry on a wet basis (obtained by drying the oven) in one batch from an initial moisture content of 87% to an end moisture content of 15% (FAO, 1997). Using equation 3.1,

\[ M_w = \frac{3 \text{ kg} \times (0.87 - 0.15)}{1 - 0.15} = 2.54 \text{ kg} \]

### 3.3 Heat Energy Required to Remove Water

The heat needed to extract water from a product was estimated using the Mercer formula (2007). The drying is considered to be a two-stage procedure where the first raises the temperature of the wet material to the appropriate level to eliminate the moisture. This is provided by:

\[ Q_1 = W_w \times C_p \times T \quad (3.2) \]

where: 
- \( C_p \) is the specific heat capacity of the produce (in kJ/kg °C) and
- \( T = T_d - T_a \), is temperature change (in °C).

The following equation may be used to calculate the specific heat capacity of a food item:

\[ C_p = 1.424 m_c + 1.549 m_p + 1.675 m_f + 0.837 m_a + 4.187 m_w + 2.0505 m_i \quad (3.3) \]

where:
- \( m_c \) = mass fraction of carbohydrate
- \( m_p \) = mass fraction of protein
- \( m_f \) = mass fraction of fat
- \( m_a \) = mass fraction of ash
- \( m_w \) = mass fraction of water
- \( m_i \) = mass fraction of ice

Chaiwanichsiri et al.(1993) provided fresh pineapples a chemical composition. If these values are used in Equation 3.3 \( C_p = 3.81 \text{ kJ/kg}^\circ \text{C} \) is given. Hence,

\[ Q_1 = 3 \text{ kg} \times 3.81 \text{ kJ/kg}^\circ \text{C} \times (45 - 25) \circ \text{C} = 228.6 \text{ kJ} \]

The second phase is the moisture evaporation of the product. As water begins to evaporate when the product is warmed up to the drying temperature, heat is provided by:

\[ Q_2 = M_w \times L \quad (3.4) \]

\( L = h_g - h_f \), is latent heat of vaporization. Damp tables are used to get values for \( h_g \) (water as vapour enthalpy) and \( h_f \) (water as liquid enthalpy) at drying temperature.

\[ h_g = 2583 \text{ kJ/kg} \quad h_f = 188 \text{ kJ/kg} \]

\[ Q_2 = 2.54 \text{ kg} \times (2583 - 188) \text{ kJ/kg} = 6083.3 \text{ kJ} \]

Therefore, the total heat requirement = \( Q_1 + Q_2 = 228.6 \text{ kJ} + 6083.3 \text{ kJ} = 6,311.9 \text{ kJ} \). The theoretical value is this value. It does not take into consideration the heat lost via the dryer walls or the heat left by the dryer.

### 3.4 Sizing the Collector

The average daily sunshine in Kumasi is 15.48 MJ/m²/day (ATPS, 2013). The average flat plate collector efficiency (25°C at ambient temperature and \( I = 400 \text{ W/m}^2 \)) is between 25 percent and 45 percent, given by the company Struckmann (2008). The efficiency of the collector is affected by variables like temperature, air flow rate, insulation, transparent material type, absorber plate and insulation utilised (Struckmann, 2008). The average collector efficiency value of 35% was used as the design parameter to create an optimum design. As a result, Daily expected energy production by the collector = 15.48 MJ/m²/day \* 0.35

\[ = 5.42 \text{ MJ/m}^2/\text{day} \]

For 2 days (the drying period), the energy production would be

\[ = 2 \times 5.42 = 10.84 \text{ MJ/m}^2 \]

Since the total heat energy required for drying is 6.31 MJ,

\[ \text{Collector Area} = \frac{6.31 \text{ MJ}}{10.84 \text{ MJ/m}^2} = 0.58 \text{ m}^2 \quad (3.5) \]

The collecting area was thus about 0.6 m². Forson et al. (2007) proposed the solar collector’s length-to-width ratio of 1-
2. In view of the ratio of 2 for this design, the collector's length and breadth was 1.1 m and 0.6 m correspondingly. Here it is important to remember that the calculations carried out are approximately fractions appropriate for building.

3.5 Collector Orientation and Tilt Angle

The flat plate solar collector should be inclined and positioned such that maximum radiation is obtained. The collector works best when it is perpendicular to the sun. The optimum angle of tilt varies by season. As a general rule, the optimal tilt angle is equal to the site's latitude (Weiss and Buchinger, 2002). A collector tilt angle of 10° was used for this design since the test location was Kumasi (Latitude 6°42’N and longitude 1°57’W) (Moujaded, 2014). This aimed to prevent the buildup of rainwater during wet times in the collector.

3.6 Air Flow Requirement

Scanlin (1997) proposes an air speed range of 0.51 m/s to 5.08 m/s. In addition, the air channel depth should be 1/15 to 1/20 of the collector length. The air channel depth is measured by the average factor of the air channel depth (0.058), as recommended by Scanlin (1997) and by the height of the collector length. Depth of air channel = 0.058 * 1.1 m

= 0.0638 m = 6.38 cm

Irwange and Adebayo (2009) also recommended that the optimal air gap should be between 4 to 8 cm between the absorber and the transparent cover. This range includes the estimated air gap of 6.38 cm.

Hence,

Vent Area = width of collector * air gap

= 60 cm * 6.38 cm = 382.8 cm² = 0.03828 m²

For an air velocity of 0.51 m/s,

Volume flow rate = Vent Area * Air Velocity

= 0.03828 m² * 0.51 m/s

= 0.0195 m³/s

By multiplying the air density by volume flow rate, 1.2 kg/m³, giving 0.0234 kg/s, the mass flow rate was obtained. This mass flow rate is within range of 0.02 – 0.9 kg/s, suggested for natural convection dryers by Forson et al. (2007).

IV. DESCRIPTION OF EXPERIMENTAL SETUP

Figure 3.1 shows the schematic design of the indirect forced solar dryer convection. The system consists of two main components, the solar air heater and the drying chamber. A single-glazed single pass forced solar convection air heater with a packed bed was utilised to raise the air temperature via the use of the sun's solar power. The solar air heater was additionally equipped with the sensitive heat storage media to keep the air exit temperature constant for drying purposes. The purpose of the drying chamber was to accommodate the drying goods and make it easier to circulate the air so that the drying process was uniform. The building material for the solar dryer was chosen carefully, taking into account life, availability and costs. Galvanized Iron sheet was used for the manufacture of a solar air heater, a drying chamber and connecting ducts. The Galvanized Iron Corrugated sheet was utilised for the absorber. Mild steel angle "L” has been utilised for the production of solar air heater and drying chamber support structures. To protect it from environmental impacts, all exposed components of the solar dryer and other support structures were painted.

Figure 1: Schematic Diagram of the Experimental Setup
Table 1: Technical Specifications of the solar air heater unit

<table>
<thead>
<tr>
<th>Type of Air Heater</th>
<th>Conventional flat plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aperture Area</td>
<td>2m²</td>
</tr>
<tr>
<td>Dimensions of the absorber plate</td>
<td>2 m × 1 m</td>
</tr>
<tr>
<td>Absorber material</td>
<td>Galvanized Iron sheet of 0.45 mm thick</td>
</tr>
<tr>
<td>Type of absorber</td>
<td>Non-porous corrugated absorber</td>
</tr>
<tr>
<td>Absorber coating</td>
<td>Black paint</td>
</tr>
<tr>
<td>Number of glazing</td>
<td>One</td>
</tr>
<tr>
<td>Glazing material</td>
<td>Plain window glass of 4 mm thick</td>
</tr>
<tr>
<td>Spacing between glazing and absorber</td>
<td>30 mm</td>
</tr>
<tr>
<td>Collector tilt angle with horizontal</td>
<td>11°</td>
</tr>
<tr>
<td>Mode of air flow</td>
<td>Forced convection</td>
</tr>
<tr>
<td>Number of air passes</td>
<td>Single-pass</td>
</tr>
<tr>
<td>Air channel duct height</td>
<td>100 mm</td>
</tr>
<tr>
<td>Back insulation</td>
<td>Glass wool of 50 mm</td>
</tr>
<tr>
<td>Side insulation</td>
<td>Glass wool of 25 mm</td>
</tr>
<tr>
<td>Blower specification</td>
<td>Single phase 0.45 kW centrifugal blower</td>
</tr>
<tr>
<td>Air flow rate range</td>
<td>Upto 290 m³/hr</td>
</tr>
<tr>
<td>Location of the test</td>
<td>Chennai</td>
</tr>
<tr>
<td>Latitude</td>
<td>11.0183° N</td>
</tr>
<tr>
<td>Longitude</td>
<td>76.9725° E</td>
</tr>
<tr>
<td>Packed Bed Material</td>
<td>Pebbles</td>
</tr>
<tr>
<td>Size of pebbles</td>
<td>Average size 30-50 mm dia (approx)</td>
</tr>
<tr>
<td>Quantity of pebbles</td>
<td>105 kg</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Figure 2: Pictorial view of the Experimental Setup

4.1 Solar Collector without Packed Bed

Figure 3 shows a typical hourly change in solar insolation, ambient temperatures, absorber plate temperature and bottom plate temperature, collector input and outlet temperature values recorded from 9 a.m. to 6 p.m. with a mass flow rate of 0.0141 kg/s on 15/04/2014. The highest solar insolation value recorded at 1.00 pm is 956 W/m². The collector’s intake temperature is constantly 2 to 6 °C higher than the ambient temperature owing to the centrifugal blower action. The ambient temperature is between 31.2 and 37.4 degrees Celsius. At the peak insolation period, the absorber plate temperature has reached the maximum value of 81.2 °C and the output temperature of the collector is recorded at 34.1 °C to 63 °C.
Figure 3: Hourly variation of solar insolation and temperature values on a typical day (15/04/2014)

Figure 4 shows the hourly change in the collector air output temperature readings for all mass flow rates. It demonstrates clearly that the outlet air temperature values vary from solar insolation. When the sun radiation is highest throughout the day, the greatest air outlet temperature is recorded. The greatest output temperature is recorded for the lowest mass air flow, while for the largest mass flow (0.0872 kg/s) the lowest temperature increase is reported. This implies that the temperature increase reduces with an increase in air mass flow. The contact time between the air and the absorber plate is due. The highest output temperature value recorded is 63 °C at a mass flow rate of 0.0141 kg/s and a maximum value of 49 °C at a mass flow rate of 0.0872 kg/s.

Figure 5: Comparison of experimental and theoretical average temperature rise of the collector with corrugated absorber plate for the range of mass flow rates

A mathematical model was created in order to determine the thermal performance of the solar collector with the corrugated absorber plate. The same was verified using actual data to verify the model's correctness. The outcomes of the anticipated experimental and theoretical values are compared. The theoretical and experimental findings of the average air temperature increase for different mass flow rates are given in Figure 5. It demonstrates that the temperature increase reduces as the mass air flow rate rises, since the residence or contact time with the (heat) surface of the absorber is lower as the air velocity increases. At a mass flow rate of 0.0141 kg/s the highest average temperature increase is 17.6 °C.
Figure 6: Comparison of Experimental and Theoretical Thermal efficiency of the collector with corrugated absorber plate for the range of mass flow rates

V. EXPERIMENTS TO FIND THERMAL STORAGE POTENTIAL OF THE SOLAR DRYER

In this experiment the solar dryer was of a cabinet type with three trays with a drying surface of 0.5 m² (each). The racks were placed equally to ensure optimum heat transfer. The plate, cans and pipes of the absorber were constructed of aluminium. The PCM utilised to store thermal products was a composite combination of paraffin (n-docosane) and kerosene. This PCM is both inexpensive and extremely efficient. Paraffin (n-docosane) is commercially available on the market. By combining kerosene adequately, the melting point may be adjusted to the desired amount.

In order to discover its melting properties, preliminary wax experiments have been performed using an electric oven with a heat entrance under a constant temperature of 60oC. Since the wax bought from the local market had a commercial quality of around 52oC, which may not alter with a sun dryer, it was decided to combine kerosene so that melting points may be reached the required level. Three PCM blends (Paraffine + Kerosene) with 1:1, 1:2 and 2:1 mixing ratios were concurrently maintained in the oven and a melting behaviour was investigated. The melting values of the combinations were 33°C, 21°C and 42°C. Based on the experiment, the 2:1 combination with melting point of 42oC is highly suited for application since it is very appropriate for solar dryer applications in this geographic region at a temperature. It was thus chosen for future testing because the system includes solar heat input. The other two mixes were not considered since their melting points were extremely low and they cannot keep the heat for significant duration in the thermal storage unit. The 2:1 PCM combination of paraffin-kerosene was utilised to sustain the process of phase transition in the appropriate temperature range.

Two types of container were used to hold the PCM which were 20 numbers of 20 mm diameter aluminium tubes of 500 mm length and 100 aluminium cans each of 49 mm diameter and 120 mm length. The PCM cans and pipelines are shown in Figures 7 and 8 correspondingly. The cans and tubes were partially filled to allow enough space for phase change thus avoiding leakage, as it will contaminate the food stuff that is kept in the dryer. Under the absorber plate, the heat storage unit was supplied. The pipes on the lower side of the absorber were placed to improve heat transmission.

On the dryer experiments were carried out to determine the temperature difference of your cabinet about the quantum fluctuation of thermal storage substance. No load and full load situations were examined. The tests were conducted in April, when sunlight stays much higher at 11.39 °N and 79.69 °E at an altitude far closer to sea level at Annamalai Nagar. Experimental observations were collected from 10 a.m. till the atmosphere arrived. The tests were conducted in peak summer on consecutive days so that solar insolation does not vary substantially.
The PCM filling procedure is shown in steps in Figure 9. As the conductivity enhancer employed has a minimal thickness, the total thermal conductivity has not occupied much area but enhanced.

VI. CONCLUSION

Food preservation mixed-mode solar dryer performance is assessed in this research. The dryer constructed after various study papers is affordable for each local and may be made from local resources. The dryer was created to preserve food from deteriorating as the region has no amenities. An indirect solar dryer was made using readily available components. The dryer is user-friendly. A carbon stove backup heater allowed continuous drying throughout the night and gloomy days. The average collector temperature was 56.4 °C, the dryer 45.1 °C, and the ambient 34.6 °C under no load. If just the backup heater was used in the evening with charcoal, the lowest tray reached 50.8 °C. This demonstrated that the dryer temperature was greater than ambient, allowing for proper drying. The drier reduced pineapple and mango moisture content from 87 percent and 85 percent to 16 percent and 15.5 percent in two to three days. The dryer performs better in hybrid mode, using charcoal as a backup heat source. Thus, pineapple and mango solar dryer drying rates rose by 26.9% and 19.8%, respectively. Without a load test, the collector was 31.5% efficient. This value fits the literature's natural convection solar dryer range. Sun drying, back-up heat throughout the drying period, and nighttime back-up heat had 9.7%, 8.7%, and 7.5% drying efficiency, respectively. The sun dryer dried pineapple and mango to the necessary moisture level for safe storage in two to three days. Due to the back-up burner’s heat, the solar dryer may be used year-round. This may protect wet-season agricultural crops. The collector with packed bed storage media is more energy efficient and reduces outlet temperature volatility. The collector's peak solar temperature rise was 31.5%, which fits the literature's natural convection solar dryer range. Sun drying, back-up heat throughout the drying period, and nighttime back-up heat had 9.7%, 8.7%, and 7.5% drying efficiency, respectively. The sun dryer dried pineapple and mango to the necessary moisture level for safe storage in two to three days. Due to the back-up burner's heat, the solar dryer may be used year-round. This may protect wet-season agricultural crops.

The collector with packed bed storage media is more energy efficient and reduces outlet temperature volatility. The collector’s peak solar temperature rise is smaller with a packed bed than without. The collector with the packed bed may operate for two more hours at 6–8 °C hotter than ambient. The mathematical models for the solar collector with and without the packed bed use steady state flow conditions, and the projected temperatures match the experimental data. The drying cabinet gathers solar energy directly through the glass ceiling and passes warm air from a second solar collector to the dryer. As indicated, this design sought to lower dryer expenses. The materials used in this design were easily accessible or affordable. The test findings showed that the dryer and solar collector were substantially hotter than the ambient temperature during most daylight hours. After 12 noon, the drying cabinet had a significant temperature increase for three hours.

- The drying chamber's average temperature is substantially higher than the atmosphere's, making a low-cost solar cabinet dryer possible. Tests indicate that the peak temperature of roughly 60 degrees C occurs around the middle of the day on sunny days.
- The combined drying mode may dry the product faster than direct and indirect drying methods. PCM mixes near the bowl and pipe walls solidify when it blends in the center.
- This is due to PCM heat resistance. The heat transfer through the previously solidified component occurs in the reverse direction as the solidification front travels to the outer surface.
- Heat gain decreases after peak sunlight due to insufficient solar insolation, but recovers due to latent heat dispensing from thermal storage material.
- Atmospheric temperature and airflow rate fluctuations cause partial storage material phase changes. The composite material's density and specific heat may be modified to satisfy Solar Dryer thermal capacity requirements by adjusting the mix ratio, reducing thermal waste.

References