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Solar Seed Dryer Using PCM Based Thermal Energy Storage System

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ABSTRACT :

This study presents a novel solar seed dryer incorporating a phase-change material (PCM)-based thermal energy storage system. The dryer aims to enhance drying efficiency and address the intermittent nature of solar energy availability. PCM is utilized to store excess thermal energy during periods of high solar irradiation, ensuring a continuous and consistent heat supply for seed drying. The design and performance of the solar seed dryer are investigated through simulations and experimental validation. Results indicate significant improvements in drying efficiency and a reduction in drying time compared to conventional solar dryers. The PCM-based thermal storage system effectively mitigates the effects of fluctuations in solar energy availability, enabling year-round operation and enhancing the dryer's reliability. This innovative approach holds promise for sustainable agricultural practices, offering a cost-effective and environmentally friendly solution for seed drying applications in regions with abundant solar resources.

Keywords: solar, seed dryer, PCM, thermal energy storage, drying efficiency, sustainable agriculture

1. INTRODUCTION

The necessity of effective farming methods and the difficulties presented by conventional seed-drying techniques that rely on fossil fuels or sporadic solar radiation are discussed in the introduction. Phase change material (PCM) technology is used in this study's innovative solar seed drier to reliably store and release thermal energy. The dryer uses PCM in conjunction with solar energy to improve drying efficiency, reduce drying time, and guarantee dependability even in the face of variations in solar irradiation. This ground-breaking method promises to transform seed drying procedures, advance agricultural sustainability, and solve energy dependency and environmental issues.

2. OBJECTIVES

- Develop a solar seed dryer integrating PCM-based thermal energy storage.
- Investigate the design parameters for optimal performance and efficiency.
- Evaluate the effectiveness of PCM in storing and releasing thermal energy.
- Assess the impact of PCM on reducing drying time and improving efficiency.
- Validate the performance of the solar seed dryer through simulations and experiments.
- Optimize the configuration to ensure consistent heat supply during fluctuating solar irradiation.
- Explore the potential for year-round operation of the dryer in diverse climatic conditions.
- Analyze the economic viability and scalability of the PCM-based solar seed dryer.
- Assess the environmental benefits, including reduced carbon emissions and energy consumption.
- Provide recommendations for practical implementation and future research directions.

3. METHODOLOGY

Design Phase:

- Determine specifications for the solar seed dryer and PCM-based thermal energy storage.
- Select appropriate materials and components for construction.

PCM Characterization:

- Identify suitable PCM materials based on thermal properties and compatibility with solar drying.
- Conduct laboratory tests to analyze PCM's melting point, latent heat capacity, and thermal stability.

Dryer Construction:

- Assemble the solar seed dryer according to design specifications.
- Integrate PCM containers into the dryer system for thermal energy storage.

Experimental Setup:

- Install sensors to measure temperature, humidity, and solar irradiation.
- Establish control parameters for monitoring and regulating dryer operation.

Testing and Validation:

- Conduct controlled drying experiments using different seed types and moisture contents.
- Compare drying performance of the PCM-based solar dryer with conventional methods.

Data Collection and Analysis:

- Record experimental data including drying time, energy consumption, and seed quality.
- Analyze results to evaluate the effectiveness of PCM in enhancing drying efficiency.

Optimization:

- Fine-tune dryer parameters based on experimental findings to maximize efficiency.
- Identify areas for improvement and potential modifications to enhance performance.

Simulation Studies:

- Utilize computer simulations to model heat transfer and drying kinetics within the solar seed dryer.
- Validate simulation results against experimental data to refine the model.

Economic and Environmental Assessment:

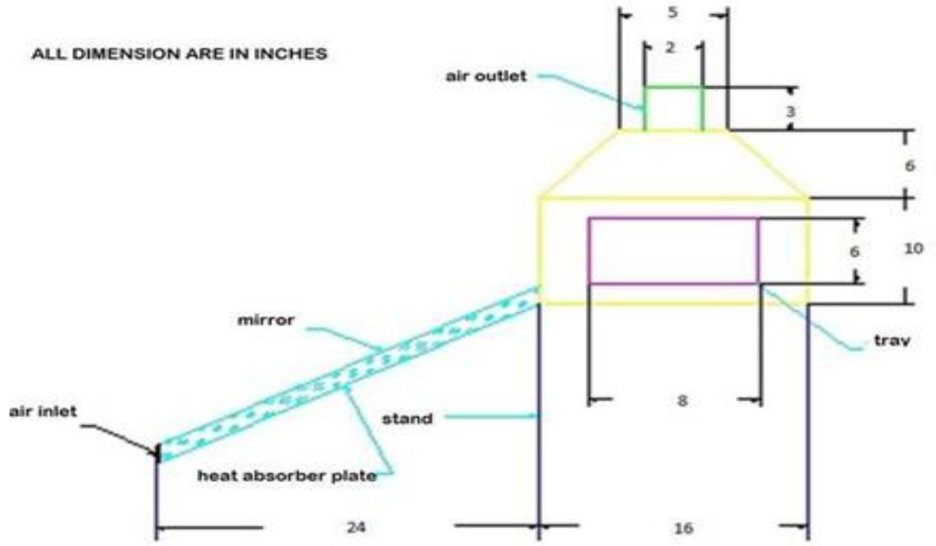
- Calculate the cost-effectiveness and payback period of the PCM-based solar dryer.
- Estimate the reduction in carbon emissions and energy savings compared to conventional drying methods.

Documentation and Reporting:

- Compile findings into a comprehensive report detailing methodology, results, and conclusions.
- Present recommendations for practical implementation and future research avenues.

4. WORKING OF SOLAR SEED DRYER

A solar seed dryer works by using the sun's radiation to create heat, which is then used to evaporate moisture from seeds. Sunlight is absorbed by solar collectors, which include parabolic trough and flat-plate collectors, and is then transformed into thermal energy. The seeds are arranged in trays or racks in the drying chamber, which receives this energy. Moisture from the seeds is absorbed by the air as it moves through the chamber and is carried out as vapor. Control systems adjust temperature and airflow to guarantee even drying. Furthermore, some solar seed dryers have thermal energy storage systems that store extra heat for use during times of low solar radiation by using phase change materials (PCMs).



Grain	Relate Humidity (%)

	30	40	50		60	70	80	90
	Equilibrium Moisture Content (%wb) at 25^0 C							
Barley	8.5	9.7	10.8	12.1	13.5	15.8	19.5	26.8
Shelled	8.3	9.8	11.2	12.9	14.0	15.6	19.6	23.8
Paddy	7.9	9.4	10.8	12.2	13.4	14.8	16.7	-
Milled	9.0	10.3	11.5	12.6	12.8	15.4	18.1	23.6
Sorghum	8.6	9.8	11.0	12.0	13.8	15.8	18.8	21.9
Wheat	8.6	9.7	10.9	11.9	13.6	15.7	19.7	25.6

Table 1. Humidity and Temperature Content

4.1 THERMAL STORAGE

Thermal energy storage (TES) plays a crucial role in enhancing the efficiency and reliability of various energy systems, including solar power plants, HVAC systems, and industrial processes. TES enables the capture and retention of excess thermal energy during periods of high availability for later use when demand exceeds supply. One prevalent method of TES involves the use of phase change materials (PCMs), substances capable of absorbing and releasing large amounts of energy during phase transitions. PCMs change state (e.g., solid to liquid) at a specific temperature, effectively storing thermal energy. Common PCMs include paraffin wax, salt hydrates, and eutectic mixtures. By incorporating PCMs into energy systems, TES facilitates load shifting, grid stabilization, and energy cost reduction. Furthermore, TES systems enhance the integration of renewable energy sources like solar and wind by mitigating intermittency issues, thereby contributing to a more sustainable and resilient energy infrastructure.

5. EXPERIMENTAL SETUP

- Solar Collector: Installation of flat-plate or parabolic trough collectors to capture solar radiation efficiently.
- Drying Chamber: Construction of a chamber designed to accommodate seeds for drying, equipped with trays or racks for seed placement.
- PCM Containers: Integration of containers filled with phase change materials (PCMs) within the drying chamber to store excess thermal energy.
- Temperature and Humidity Sensors: Placement of sensors throughout the drying chamber to monitor environmental conditions.
- Data Acquisition System: Implementation of a data acquisition system to collect real-time data from the sensors.
- Control System: Incorporation of a control system to regulate airflow, temperature, and humidity within the drying chamber.
- Solar Irradiance Measurement: Installation of sensors to measure incident solar radiation for precise energy input calculations.
- Air Circulation System: Implementation of fans or blowers to ensure uniform airflow distribution within the drying chamber.
- Safety Measures: Adoption of safety protocols to mitigate risks associated with experimental procedures and equipment operation.
- Replicability: Ensuring the setup can be replicated to conduct multiple trials under consistent conditions for reliable results.

Renewable and Sustainable Energy				
A list of selected solid–liquid materials for sensible heat storage.				
Medium	Fluid type	Temperature range (8C)	Density (kg/m3)	Specific heat (J/kg K)
Rock		20	2560	879
Brick		20	1600	840
Concrete		20	1900–2300	880
Water		0–100	1000	4190
Caloriea HT43	Oil	12–260	867	2200
Engine oil	Oil	Up to 160	888	1880
Ethanol	Organic liquid	Up to 78	790	2400
Propanol	Organic liquid	Up to 97	800	2500
Butanol	Organic liquid	Up to 118	809	2400
Isobutanol	Organic liquid	Up to 100	808	3000
Isopentanol	Organic liquid	Up to 148	831	2200
Octane	Organic liquid	Up to 126	704	2400

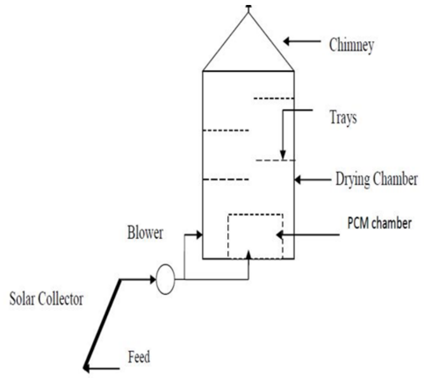


Fig 2: Layout of the project

5.2 DESIGN SPECIFICATION A DRYING CHAMBER

Dryer having a size 75cm x 75cm x 90cm was made by locally available plywood, which consist of 3 tray. Capacity of the dryer is 5kg. The upper most part of the drying chamber is covered with hollow transparent polycarbonate sheet

SOLAR COLLECTOR:

To find out the amount of heat required to remove moisture:
Material to be dried = Cassava root
Moisture content in raw cassava = 62-65 %
Moisture content in stable = 14%
The amount of moisture content removed from wet material is given by,
Mm = m (wt% - dry%) kg
(100% - dry%)
5 x (0.62 – 0.14)/ (1-0.14)
2.8 Kg
We have to remove 2.8 Kg of water from 5 Kg raw material in order to get the required value added product.
Amount of heat required to remove moisture content is given by,
QR = Mm x hfg + Mm x hf
Where,
hfg = Latent heat of evaporation of water.
From steam tables ,at 100^0C, hfg = 2256.4 KJ/KG hf =Enthalpy of water.
From steam tables, at 100^0C, hf = 419.17 KJ/Kg QR = 2.8 x 2256.4 + 2.8 x 419.17
=7491.6 KJ
=7491.6/ (60 x 60x 12)
=173.4 W

To find out area of flat plate collector:
The useful amount of heat delivered by a flat plate is given by,
Qu = Ac [It. (τ.α) – UL (Tp – Ta)] FR Where,
Ac = Collector area, m^2
It = Solar irradiance = 420 W/m^2
= Transmissivity = 0.88 α = absorptivity = 0.9
UL = Overall heat loss coefficient = 5 $W/m^2 \, {}^0C$
Tp =Average temperature at upper surface of the absorber = 45^0C
Ta =Average atmospheric temperature = 20^0C
Qu = Ac [420 x 0.88 x 0.9 – 5 (45-20)] x 0.9
= Ac x 186.9 W
For our design purpose,
QR = Qu
From the above, we get area of collector,
Ac = 173.4/186.9
= 0.93 m^2
Taking approximate value, the collector size = 1 m^2.

In order to make a solar air heater a more effective solar energy utilization system, thermal performance needs to be improved by enhancing the heat transfer rate from absorber plate to air flowing in the duct of solar air heater. One of the methods for the enhancement of convective heat transfer is by creating turbulence at heat transfer surface with the help of artificial roughness on absorber plate. The baffles made the air to follow a winding path, thereby doubling the length of the air passage through the collector. The baffles were positioned vertically upward pointing to the glass plate. The baffles create turbulence which forces the air to come in close contact with hot surface of the absorber and decreases the thermal sub layer. There will be a considerable improvement in the collector efficiency of solar air heaters if the fins in the collector have attached baffles to create air turbulence and an extended heat-transfer area.

TRAYS:

Drying chamber designed in such way that it consist 3 trays of 70 cm x 70 cm x2 cm size, which would hold up to 5 kg of drying products. The trays are made of aluminum mesh to avoid rusting.

PCM CHAMBER:

In an indirect solar dryer (ISD), the PCM storage unit is located at the inner bottom of the drying compartment to reduce the heat losses. No insulation is provided for the PCM chamber since it is place inside the dryer.

The quantity of PCM required is calculated as:

Latent heat capacity of Paraffin wax = 220 KJ/Kg

Required amount of energy= 7491.6 KJ

Amount of PCM required = 7491.6/220 = 34Kg

For extension of working of dryer to one more hour amount of PCM required = 34/12 (12 hours) =2.8 Kg

We chose 3 Kg of paraffin wax

6. RESULT AND DISCUSSION

The investigation encompasses two approaches: open and closed drying systems. Additionally, a comparative analysis between sensible and latent heat storage systems is undertaken. This solar dryer incorporates a thermal storage unit, capturing and retaining heat during daylight hours for subsequent use during periods of low solar intensity or nighttime. Experimental trials are conducted utilizing both sensible (pebble-based) and latent (paraffin wax) energy storage systems, facilitating a comprehensive comparative assessment of their efficacy.

7. CONCLUSION

The research project is aimed at designing and fabricating an efficient solar dryer. The constructed dryer is to be used to dry agricultural products under controlled and protected conditions. The drying system proved efficient and economical for drying agricultural products. The experiments were conducted on potato and cassava roots. Since the product was not directly exposed to solar radiation, the color of the product was retained even after complete drying. The energy balance equations were developed for the solar air heater. The selection of paraffin wax as PCM gives the advantage of storing solar energy even after sunset for a few hours. It is inferred that using high-temperature conductive particles with paraffin wax as energy storage material may improve the thermal performance of the indirect solar dryer. The capital investment of the dryer was Rs. 30 000, and the payback period of the dryer was found to be 0.578 years, which is very short considering the life of the system.

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