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ECONOMIC ANALYSIS OF SOLAR DRYER WITH PCM FOR DRYING AGRICULTURAL PRODUCTS

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Abstract - *Solar energy is the most readily available source of energy. It is also the most important of the non-conventional sources of energy because it is non-polluting and therefore helps in lessening the greenhouse effect. Drying by exposure to the sun is one of the oldest method using solar energy for food preservation such as vegetables, fruits, fish etc. This project objective is to develop a solar dryer incorporated with PCM for drying agricultural products. Developing efficient and inexpensive energy storage device in solar dryer is as important as developing new sources of energy and reduces the time between energy supply and energy demand there by playing a vital role in energy conservation. The design utilizes the indirect solar heating principle, which means the heat is transferred to material to be dried by a fluid medium (air). A flat plate solar collector used to absorb the heat. The absorbed heat has to be transferred to the drying compartment with a blower. The blower sucks heated air and delivers to drying compartment via Paraffin PCM (Phase Changing Material) and the drying is done by hot air. At the same time heat energy will be stored in PCM. The Paraffin present in the PCM chamber in solid phase turns to liquid phase by absorbing the heat. So when the solar radiation becomes nil, the drying takes place by using the heat stored in PCM. The dry heated air removes the moisture from the material to be dried and is exhausted via chimney. Generally two methods are used for the economic analysis. The first method is the life cycle saving method and the second method, namely payback period method. In this experiment t the economic analysis of the solar dryer is conducting by payback period method. Based on the information on production scales, operating costs of the dryer and price of the dried products, the payback period of the solar dryer can be calculated.*

Key Words: Solar air heater, cassava root, drying chamber, Paraffin wax, solar panel, blower.

1. INTRODUCTION

Sun drying is the earliest method of drying farm produce ever known to man and it involves simply laying the agricultural products in the sun on mats , roofs or drying floors. This has several disadvantages since the farm produce are laid in the open sky and there is greater risk of spoilage due to adverse climatic conditions like rain, wind, moist and dust, loss of produce to birds, insects and rodents (pests); totally dependent on good weather and very slow drying rate with danger of mould growth thereby causing deterioration and decomposition of the produce. The process also requires large area of land , takes time and highly labour intensive. Recently, efforts to improve sun drying have led to solar drying. In solar drying, solar dryers are specialized devices that control the drying process and protect agricultural produce from damage by insect, pests, dust and rain. In comparison to natural open drying, solar dryers generate higher temperatures, lower relative humidity, and lower product moisture content and reduced spoilage during the drying process. In addition it takes up less space, takes less time and relatively inexpensive compared to artificial mechanical drying method. Thus solar drying is a better alternative solution to all the drawbacks of natural drying and artificial mechanical drying.

The solar dryer can be seen as one of the solutions to the world's food and energy crises. With drying most agricultural produce can be preserved and this can be achieved more efficiently through the use of solar dryers.

The intermittent nature of the solar energy which is the main source of energy in solar drying is indeed one of the major shortcomings of the solar drying system. It can be alleviated by storing excess energy during the peak time and use it in off sun hours or when the energy availability is inadequate. Developing efficient and inexpensive energy storage device in solar dryer is as important as developing new sources of energy and reduces the time between energy supply and energy demand thereby playing a vital role in energy conservation. It improves the energy systems by smoothing the output and thus increases in the reliability. Thermal energy from the sun can be stored in many ways. One of the most promising technologies for storing thermal energy is the latent heat storage systems using phase change materials (PCM). The main advantage of latent heat storage systems over sensible heat storage systems is that the volume required for storing is very small thereby reducing the losses during charging and discharging.

2. SOLAR DRYER

Solar dryers can be proved to be most useful device from energy conservation point of view. It not only save energy but also save lot of time, occupying less area, improves quality of the product, makes the process more efficient and protects environment also. Solar dryers circumvent some of the major disadvantages of classical drying. Solar drying can be used for the entire drying process or for supplementing artificial drying systems thus reducing the total amount of fuel energy required.

Solar dryer is a very useful device for

1. Agriculture crop drying
2. Food processing industries for dehydration of fruits, potatoes, onions and other vegetables
3. Dairy industries for production of milk powder, casein etc.
4. Seasoning of wood and timber.
5. Textile industries for drying of textile materials.

2.1 TYPES OF SOLAR DRYER

Solar energy drying systems are classified primarily according to their heating modes and the manner in which the solar heat is utilized. In broad terms, they can be classified into two major groups, namely

1. Active solar energy drying systems
2. Passive solar energy drying systems

Three distinct sub classes of either the active or passive solar drying systems can be identified which vary mainly in the design arrangement of system components and the mode of utilization of the solar heat, namely

A. Direct solar dryers
B. Indirect (distributed) solar dryers
C. Mixed-mode solar dryers

A. DIRECT SOLAR DRYER

In this kind of solar dryer a transparent cover is used to reduce heat losses and it simultaneously gives the product assertive protection from rain and dust. Aeration required for removing the evaporated water is provided by ascending air forces. However in this type of process avoiding infestations is impossible. The best example of a direct type solar dryer is a box type or cabinet dryer. A direct type solar dryer is commonly used in areas that receive direct sunlight for longer periods during the day. Here the drying cabinet is constructed from 1 cm-thick pressed wood and is fully insulated by glass wool on the inside, back, and bottom walls. The slanted front wall is covered by a thick glass sheet to allow sunlight to pass through. This transparent wall may be covered with an opaque and insulated sheet for an indirect mode of dryer application. The back side of the dryer has exhaust holes through which humid air is sucked out by a fan. The lowest part of the front wall is made in such a way that it can redirect hot air from the solar collector into the chamber using a centrifugal blower.

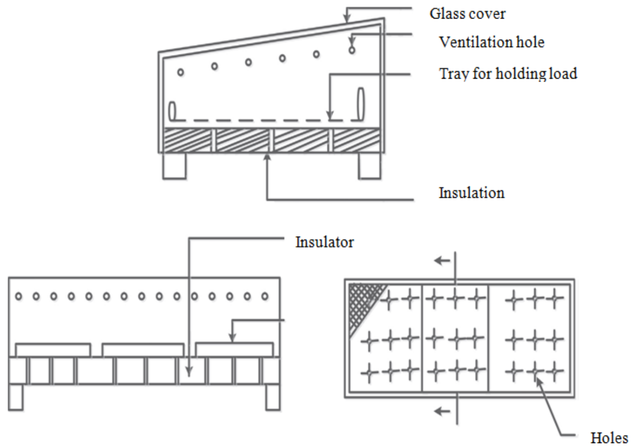

Fig-1: Direct Solar Dryer

B. INDIRECT SOLAR DRYER

In an indirect solar dryer, the solar radiation is first collected by the solar collectors and is then passed on to the dryer cabinet where the drying occurs. The basic concept of reverse flat plate collector is used to dry food products in a solar cabinet type dryer. Here a solar air heater is used to heat the air that enters the chamber. The heated air then turns into warm humid air which passes through an outlet. This kind of dryer is better than other dryers in terms of solving various equations based on energy balance. It also has better performance than other conventional cabinet type of dryers. Under unfavourable weather situations this drying unit can still produce good quality products.

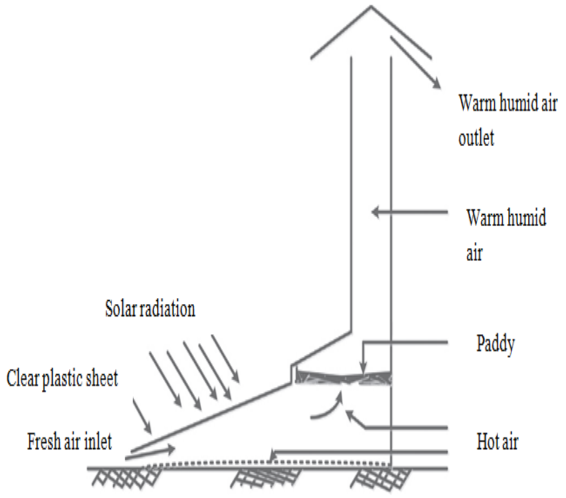

Fig-2:Indirect Solar Dryer

C. MIXED MODE SOLAR DRYER

The mixed-mode solar dryer has no moving parts so it is called the passive dryer. This type of dryer acquires energy from the rays of the sun that enters through the collector lustring. The inside surface of the collector is painted black and the sun rays are harnessed by trapping the heat f the air that is collected inside the chamber. This kind of solar dryer verified the accelerated drying process and its ability to dry agricultural products by quickly reaching better conditional moisture level, thus making it ideal for food preservation. This kind of dryer consists of a separate solar collector and a drying unit. A transparent cover is affixed on top of the dryer, the solar collector, and the drying unit. The collector receives the solar radiation. This kind of dryer is often used for drying crops in the wet season. Comparing the three kinds of dryers, the mixed-mode dryer is the best of the three because it has the highest drying rate followed by the box dryer.

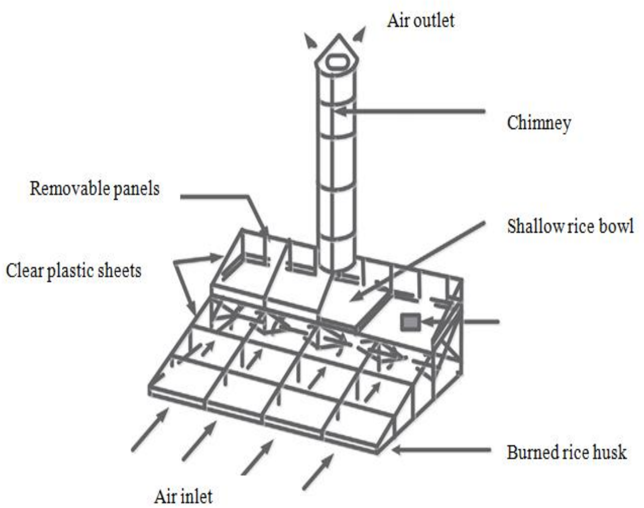

Fig-3: Mixed Mode Solar Dryer

3. THERMAL ENERGY STORAGE SYSTEM

Thermal energy storage through PCM is capable of storing and releasing large amounts of energy. The system depends on the shift in phase of the material for holding and releasing the energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. Therefore, PCMs readily and predictably change their phase with a certain input of energy and release this energy at a later time.. Compared to the storage of sensible heat there is no temperature change in the storage. Thermal energy storage can be stored as a change in internal energy of a material as sensible heat, latent heat and thermochemical or combination of these.

A .SENSIBLE HEAT STORAGE

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a material practically a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material.

B. LATENT HEAT STORAGE

Latent heat storage (LHS) is based on the heat absorption or release when a storage material undergoes a phase change from solid to liquid or liquid to gas or vice versa.

4. EXPERIMENTAL SETUP

The conventional dryer is not reliable. Increasing the collector area increases the area available for insolation and thus reduces the drying time. However increased collector area subsequently leads to increased capital cost and more space required for a larger solar dryer. By incorporating storage system along with the conventional solar dryer this mismatch between supply and demand can be solved to an extent. The objective of this set up is to improve upon the existing methods of solar drying by using energy storage system and to determine if there is an improvement in the drying performance of agricultural products.

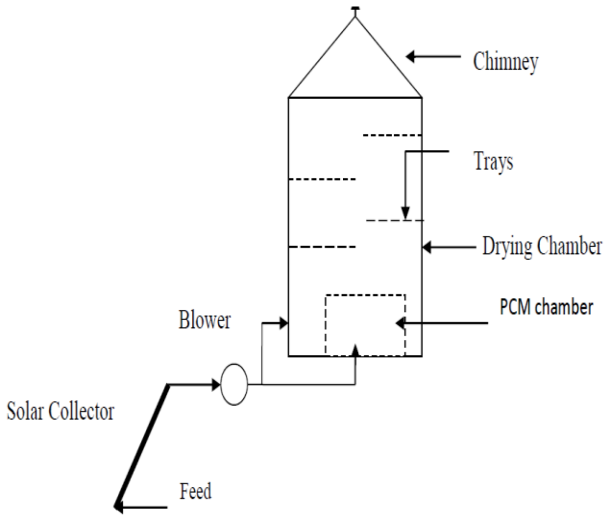

Fig 4: Layout of the Project

The solar dryer consist of an inclined solar air heater with PCM located inside the drying chamber. The blower delivers a constant air mass flow rate to the drying chamber. The air passes through the solar air heater which heats the air and the heated air is allowed to flow into the drying chamber. When the air in the heater gets heated up and reaches the critical point of PCM they will melt and charging takes place. When the sunlight is not abundant the air temperature flowing inside the heater will reduce and thus the PCM will starts to freeze and thus discharging takes place. During discharging the PCM will freeze slowly and thus the dryer will get heat air for a longer time. The heated air from the air heater flows through a drying chamber whose walls are coated with aluminum paint to avoid heat losses. Inside the chamber there is a tray in which the products to be dried are held. Due to the movement heated air over the tray the products gets dried. The fan inside the chamber forces the ambient air to pass through the collector and rise up to the product being dried. The phase changing material (PCM) used in this work is paraffin wax. Paraffin wax is a white or colorless soft solid derivable from petroleum, coal or oil shale. Paraffin wax is mostly found as a white, odorless, tasteless, waxy solid, with a typical melting point between about 40 and 68 °C. It is mainly used in a pathology laboratory, industrial application etc.

5. 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

B. 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,

$$Mm = \frac{m\,(wt\% - dry\%)}{(100\% - dry\%)}\ kg$$

$$= 5 \times (0.62 - 0.14) / (1 - 0.14)$$

$$= 2.8\ Kg$$

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^{0}C, hfg = 2256.4 KJ/KG

hf =Enthalpy of water.

From steam tables, at 100^{0}C, 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,

$$Qu = Ac\,[It.\,(\tau.\alpha) - UL\,(Tp - Ta)]\,FR$$

Where,

Ac = Collector area, m^2

It = Solar irradiance = 420 W/m^2

τ = Transmissivity = 0.88

α = absorptivity = 0.9

UL = Overall heat loss coefficient = 5 W/m^2 ^{0}C

Tp =Average temperature at upper surface of the absorber = 45^{0}C

Ta =Average atmospheric temperature = 20^{0}C

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.

C. 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.

D. 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. EXPERIMENTAL SETUP

The analysis of the system was conducted at an open ground, in front of Automobile lab, Nehru College of Engineering and Research Centre from April to May. The solar dryer was placed outside with the collector facing the direction of the sun. The area has a temperature of 33-36^{o}C. The global solar radiation, *I*, was measured using a high precision pyranometer. The dryer was evaluated using five kilogram (5 kg) of freshly harvested cassava root and potato with initial moisture content of 58%. The products were arranged on the drying trays in a single layer to avoid moisture being trapped in the lower layer. The dryer chamber door was closed and seals placed in position. The same quantity of cassava root and potato at same moisture content was sun dried to allow comparison of the two drying modes. The experiment was done several times with the moisture content of both the product being measured from daily in morning 10:00am to evening 4.00pm during the drying process to determine the number of days to attain the moisture content of 14%. The collector inlet, storage unit and drying chamber temperatures were all manually measured using a temperature gauge hourly between 10:00am to 4.00pm.

Fig 6: Experimental Setup of Solar Dryer

7. RESULT AND DISCUSSION

Analysis of the system is carried out in two methods: open drying system and closed drying system. A comparative study of the sensible energy storage system and latent heat storage system is also conducted.

This solar dryer was developed with a thermal storage system. The storage unit stores the heat in thermal storage system during the day and supplies hot air during the night and overcast periods. In this work, the experiments were conducted with both sensible energy storage system (pebbles) and latent heat energy storage system (paraffin wax) and made a comparative study with both thermal energy storage systems.

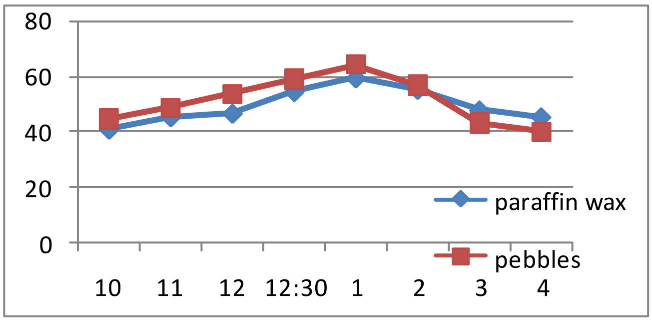

Fig.7. Temperature Variation in SHS and LHS

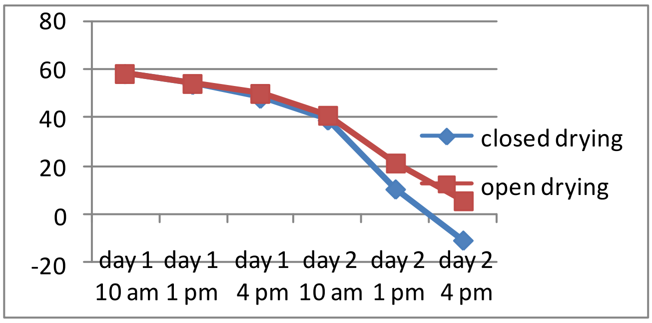

Fig.8. Reduced Moisture Content in Closed Drying Vs Open Drying

8. CONCLUSION

The research project is aimed for 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 economic for drying agricultural products. The experiments were conducted on potato and cassava root. 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 solar air heater. The selection of paraffin wax as PCM gives an advantage of storing the solar energy even after the sunset, for few hours. It is inferred that using high thermal 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 year, which is very short considering the life of the system.

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