THERMAL SOLAR DRYER USING PHASE CHANGE MATERIAL

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I. ABSTRACT

Drying crops by solar energy is of great economic importance the world over, especially in India where most of the crops and grain harvests are lost to fungal and microbial attacks. Proper drying could easily prevent these wastages, which enhances storage of crops and grains over long periods. India is blessed with abundant solar energy all the year round. Drying is one of the important and most energy consuming processes in the food-processing, chemical, printing, fabric dying industries, etc. In farmer level drying is being done on open yards without any good hygienic conditions. The objective of this project is to modify design of a forced convection indirect solar dryer and its performance test on Grapes and etc. The hot air passed to the required place, so that the moisture contents in the place was removed. It offers a better control over drying and the product obtained is of better quality than sun drying. Solar Dryer Can be operated at higher temperature, recommended for deep layer drying. In this project designed, New solar dryer with Phase Change Material for off sun shine timings. 1.2*1 m2 area of conventional solar dryer designed with 3.5kg of PCM (Sodiumthiosulphate pentahydrate and Disodium hydrogen phosphate decacohydrate) for 5kg of drying products. The Performance are experimentally conducted in on shine and off shine periods. The solar dryer consists of different components such as wood, Glass ,Copper tube, Metal Sheet, Galvanization Iron and Phase Change Material.

KEYWORDS-- Solar Collector, drying chamber, Copper tubes, phase change material and drying products.

II. INTRODUCTION

In most of developing countries a large amount of food and grains are spoiled due to the lack of proper storage system. Drying of food is an effective means of extending life of food, improving quality and minimizing losses during most of the water is taken out from the product during process. The conventional dryer system to preserve fruits, vegetables, grains and other agricultural products is sun drying which is free and renewable energy source. But, for large production there are various limitations of sun drying as damage to the products by animals and birds. There is also a chance of growth of microorganism due to non-uniform drying. The advancement of sun drying is solar drying system in which products are dried in a closed system in which inside temperature is higher. As this technique needs no energy during day time is most beneficial to small scale production. If necessary to dry product in night time and bad weather, an additionally Phase Change Material (PCM) can be used for heat supply.

A. SOLAR COLLECTOR

Solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or roof

B. DRYING CHAMBER

Drying chambers are used whenever a particularly low level of humidity is required, whether it is for storing food or dehumidifying test objects. Alongside drying and storage, modern drying chambers also enable more complex applications, such as simulating aging processes and carrying out general material testing.

C. PHASE CHANGE MATERIAL

A phase change material (PCM) is a substance with a high heat of fusion which, melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa; thus, PCMs are classified as latent heat storage (LHS) unit

D. COMPONENTS

The basic components of a thermal solar dryer

1. Solar Collector
2. Drying chamber
3. Copper pipe
4. Phase Change Materials
   - DiSodium Hydrogen Phosphate Decacohydrate
   - Sodium Thiosulphate Pentahydrate
5. Sensors
6. Insulation Tape

III. LITERATURE REVIEW

Rajkumar et al[1] Crop drying is the most energy consuming process in all processes on the farm. The purpose of drying is to remove moisture from the agricultural produce so that it can be processed safely and stored for increased periods. Crops can also dry before storage or, during storage, by forced circulation of air, to prevent spontaneous combustion by inhibiting fermentation. It is estimated that 20% of the world‘s grain production is lost after harvest because of inefficient handling and poor implementation of post-harvest technology, says Hartman‘s (1991). Grains and seeds are normally harvested at a moisture level between 18% and 40% depending on the nature of crop. These must be dried to a level of 7% to 11% depending on application and market need. Once a cereal crop is harvested, it may have to be stored for a period before it can be marketed or used as feed. The length of time a cereal can be safely stored will depend on the condition it was harvested and the type of storage facility being utilized. Grains stored and moisture contents can be kept in storage for longer period before its quality will deteriorate. Some of the cereals that are normally stored include maize, rice, beans.

Ibrahim et al[2] Passive dryers can be further divided into direct and indirect models A direct solar dryer is a system in which the food is directly exposed to the solar radiations only in which the material to be dried are placed in a transparent enclosure of glass or plastic or with reflected radiations such as box dryer. Reflected radiations are used to increase the temperature in the box dryer. In direct solar dryers, the air heater contains the grains and solar energy, which passes through a transparent cover and is absorbed by the grains. Essentially, the heat required for drying is provided by radiation to the upper layers and subsequent conduction into the grain bed. However, in an indirect solar dryer, solar radiation do not falls directly onto the product being dried, but collector is used to raise the hot air temperature in the dryer chamber. in indirect dryers, solar energy is collected in a separate solar collector (air heater) and the heated air then passes through the grain bed, while in the mixed-mode type of dryer, the heated air from a separate solar collector is passed through a grain bed, and at the same time, the drying cabinet absorbs solar energy directly through the transparent walls or the roof.

Banout et al[3] Energy is important for the existence and development of human kind and is a key issue in international politics, the economy, military preparedness, and diplomacy. To reduce the impact of conventional energy sources on the environment, much attention should be paid to the development of new energy and renewable energy resources. Solar energy, which is environment friendly, is renewable and can serve as a sustainable energy source.

Boughali et al[4] Solar energy is free, environmentally clean, and therefore is recognized as one of the most promising alternative energy recourses options. In near future, the large-scale introduction of solar energy systems, directly converting solar radiation into heat, can be looked forward. However, solar energy is intermittent by its nature; there is no sun at night. Its total available value is seasonal and is dependent on the meteorological conditions of the location. Unreliability is the biggest retarding factor for extensive solar energy utilization. Of course, reliability of solar energy can be increased by storing its portion when it is in excess of the load and using the stored energy whenever needed.

Solar drying is a potential decentralized thermal application of solar energy particularly in developing countries [4]. However, so far, there has been very little field penetration of solar drying technology. In the initial phase of dissemination, identification of suitable areas for using solar dryers would be extremely helpful towards their market penetration.

Chapman et al[5] Solar drying is often differentiated from sun drying‖ by the use of equipment to collect the sun‘s radiation in order to harness the radiative energy for drying applications. Sun drying is a common farming and agricultural process in many countries, particularly where the outdoor temperature reaches 30oC or higher. In many parts of South East Asia, spice s and herbs are routinely dried. However, weather conditions often preclude the use of sun drying because of spoilage due to rehydration during unexpected rainy days. Furthermore, any direct exposure to the sun during high temperature days might cause case hardening, where a hard shell develops on the outside of the agricultural products, trapping moisture inside. Therefore, the employment of solar dryer taps on the freely available sun energy while ensuring good product quality via judicious control of the radiative heat. Solar energy has been used throughout the world to dry products. Such is the diversity of solar dryers that commonly solar-dried products include grains, fruits, meat, vegetables and fish. A typical solar dryer improves upon the traditional open-air sun system in five important ways [4]

E. OBJECTIVE

The objective of solar dryer is to provide amount of heat more than ambient heat under given humidity. It increases the vapour pressure of the moisture confined within the product and decreases the relative humidity of the drying air so that the moisture carrying capacity of the air can be increased.

Air drawnthrough the dryer by naturalconvectional method. It is heated as it passes through the collector and then partially cooled as it catches moisture from product. Warm air can hold more moisture removed depends on the temperature to which it is heated in the collector. The product is heated both directly sun, by warm air as well as phase change material during off sun shine

IV. METHODOLOGY

The design methodology is mainly used for drying the agriculture products both on and off sunshine periods using Phase Change Material. The solar dryer is operated using sun light energy. The air inside the solar collector absorbed heat energy from the sun by the principle of l heat transfer as well as the Phase Change Material placed inside the copper tubes absorbed heat energy by phase change property from solid to liquid state by the principle latent heat. The warm air in the collector is used to dry the products inside the drying chamber. Drying is commonly described as the operation of thermally removing water content to yield dried products. Drying is transfer of heat energy from surrounding to evaporate the moisture from the surface and also transfer of internal moisture to the surface of the solid and subsequent evaporation due to application heat energy from Sun during sunshine period. After sunshine period the energy stored in Phase Change Material are liberate stored heat energy to the surrounding air by the property of latent heat this warm air dried products during off sunshine period.

The testing methodology carried out in such ways that design the solar collector to remove moisture content in the agricultural products. Efficiency of the dryer and the collector with implementation of Phase Change Material in developed solar dryer.

1. Testing has been carried out for drying of products from the initial moisture content of 60% to final moisture content up to 15% with implementation of a Phase Change Material.
2. The temperatures of collector, drying chamber, ambient temperature and Phase Change temperature.

V. WORKING PRINCIPLE

A. Heat transfer

Heat transfer is the movement of thermal energy from one thing to another thing of different temperature

1. Conduction (Direct conduct in same phase)
2. Convection (Between two different phase)
3. Radiation (Electromagnetic waves)

B. Latent heat

It is the phenomenon in which the thermal energy released or absorbed, by a body or a thermodynamic system, during a constant temperature process.

C. Sensible heat

It is heat exchange by a body or thermodynamic system in which the exchange of heat changes the temperature of the body or system.

D. Working Procedure

The principle of the solar dryer technique is to collect solar energy by heating-up the volume of air in solar collector and conduct the hot air from the collector to an attached enclosure, the drying chamber.

- The air inside the collector is absorbed energy from the sun.
- The Phase Change Material also absorbed energy from the sun by phase change.
- The hot air in the collector is then dried the products in the dryer during sunshine.
- During after sunshine the stored energy in the Phase Change Material is used to dry the products.

VI. DESIGN CALCULATION

Pipe Length L = 1m
Inner Diameter d_i = 34.8 mm = 0.0348m
Product = 5Kg
Breadth =1m
Ambient Temperature = 30^0c
Time = 12 hrs

MATERIAL USED

Copper
Thermal conductivity, K_{cu} = 400 W/mK
Galvanized iron
Thermal conductivity K_{gi} = 84 W/Mk

A. ANGLE TO TILT (B) OF SOLAR COLLECTOR

$$\beta=10^0+\phi$$

Where ϕ=>Latitude of Solar Collector location For Chennai $\phi=13.09^0$

$$\beta=10^0+13.09^0$$

$$\boldsymbol{\beta=23.09^0}$$

B. ISOLATION ON SOLAR COLLECTOR

Average daily horizontal radiation,

H=5.77 KWh/m^2/day

$$H=\frac{5.77x24x3600x10^3}{3600}$$

$$\mathbf{H=585\ W/m^2}$$

Isolation of Solar Collector =**H x R x η_c**
Average effective radiation, R=0.95 Efficiency of Solar Collector setup =80%

I_c =585 x 0.95 x0.80

$$\mathbf{I_c=450\ W/m^2}$$

C. MASS FLOW RATE OF AIR

Air gap
Height, h=6 cm =0.06 m
Width, w=80 cm =0.8 m
Volumetric flow rate of air **$V'_a=v_a$ x h x w**
Average velocity of air, v_a =2.08 m/s

V'_a=2.08 x 0.06 x 0.8

$$\mathbf{V'_a=0.09984m^3/s}$$

Mass flow rate of air, **$\dot{m}_a=V'_a$ x ρ_a**

Where ρ_a => Density of air at Standard Temperature and Pressure (STP)

$\dot{m}_A$=0.09984 X 1.2252

$$\mathbf{\dot{m}_a=0.122Kg/s}$$

D. DRYER UNIT

Mass of the product, m=5Kg Moisture content =60% Moisture content in stable =15% Amount of moisture to remove,

$m_r=m_{(\ \ \%-\ \ \%)}^{(\ \ \%-\ \ \%)}$

$m_r=5_{(100\%=15\%)}^{(60\%-15\%)}$

$$\mathbf{m_r=2.65Kg}$$

Mass of water 2.65 Kg is removed from 5 Kg of product.

Amount of heat required to remove moisture, **$Q_r= m_r$ x h_{fg}+ m_r x h_f**

$Q_r= m_r$ x (h_{fg} + h_f)

From steam table, at temperature 60^0c

h_f= 251.1 KJ/Kg

h_{fg}= 2358.6 KJ/Kg

Q_r= 2.65 x (2358.6 + 251.1)

= 6915.7 KJ

$$\mathbf{Q_r=6950\ KJ}$$

For working of 12 hours, t=12 x 60 x 60 =43200 seconds

$$= \frac{}{} = \frac{6950\ 10^3}{42300} = 160.88\ W$$

= 165 W

Useful heat in air= Energy gain in air – Energy loss in air

$= A_C I_C \eta_C \tau\alpha - U_L A_C (T_C - T_\infty)$

Where Transmit, τ=0.8

Absorptity of Galvanized sheet metal, α=0.65 Overall heat transfer coefficient, U_L= 6 W/m^2K Solar collector air temperature, T_C= 45^0c Outside air temperature, T_∞= 30^0c

= A_C (450 x 0.8 x 0.65 – 6 x 15) **=144A_C**

From Energy Balance,Heat required to remove moisture = Useful Heat in air

165= 144 x A_C

A_C= 1.14 m^2

A_C=1.2m^2

Let us consider the Breadth of the collector, B =1 m

A_C=L x B

1.2=L x 1

L=1.2 m

Length of the Solar collector, L=1.2 m Heat gain in a collector, **$= I_C A_C \eta_C \tau\alpha$**

=450x1.2x0.8x0.65

=280 W

Heat loss, **$= U_L A_C (T_C - T_\infty)$**

=6 x 1.2 x 15

=108 W

Useful heat in air, =280-108

=

E. COPPER TUBE DIMENSION

Copper tube outer diameter, D=2 cm=0.02 m

Useful heat in air **$= h A (T_C - T_\infty)$**

=172 W

A=0.096 m^2

π x 0.02 x L=0.096

L=1.53m

F. THERMAL STORAGE

Dimension of tray =1 x 0.5 x 0.025 m^3

PCM= THIOSODIUM HYDROGEN PHOSPHATE PENTAHYDRATE

T_{melt} = 50^0C

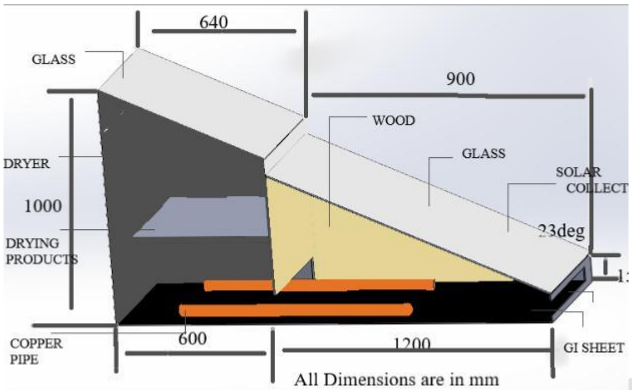
Heat storage capacity = 180 KJ/Kg

Required amount of heat = 6950 KJ

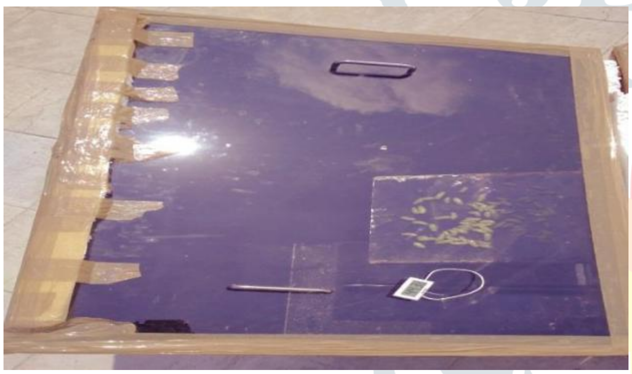
PCM required $= \frac{6950}{180}$ =38.61Kg

Working of PCM for dryer per hour = $\frac{38.61}{12}$ =3.21Kg

VII. DESIGN CROSS SECTION VIEW



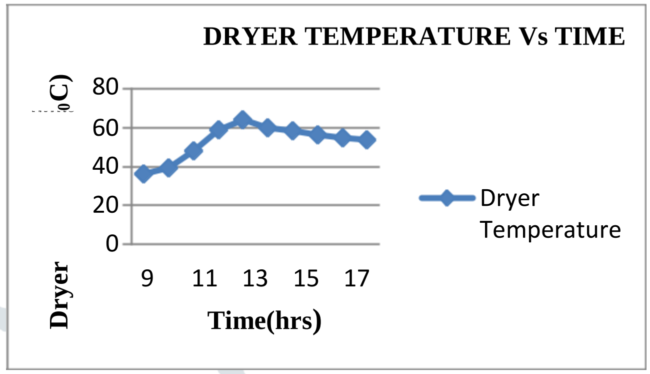
A. DRYING CHAMBER

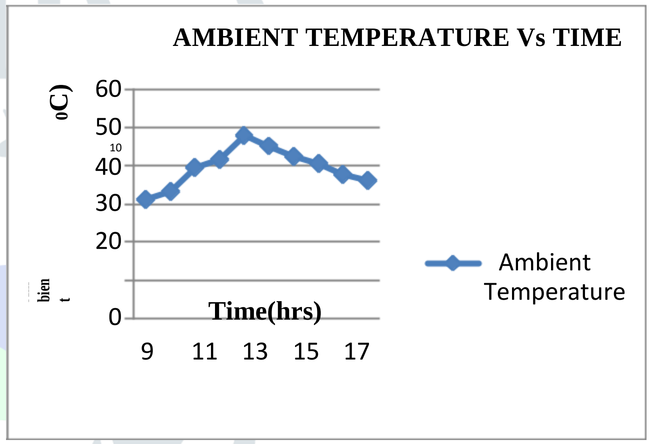


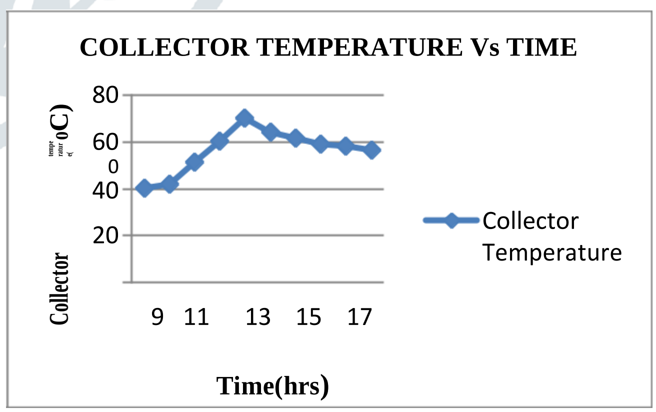
B. ASSEMBLE VIEW

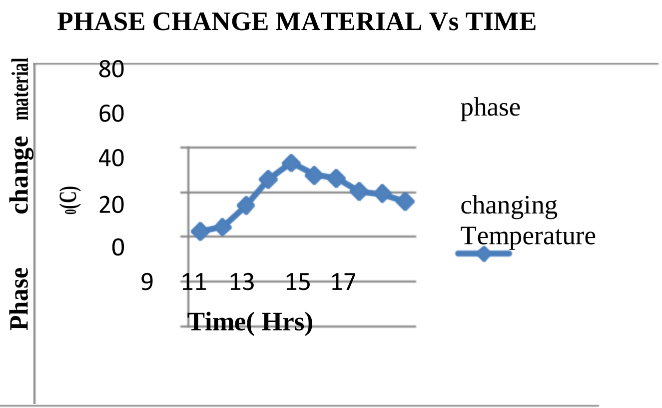
VIII. TESTING RESULT

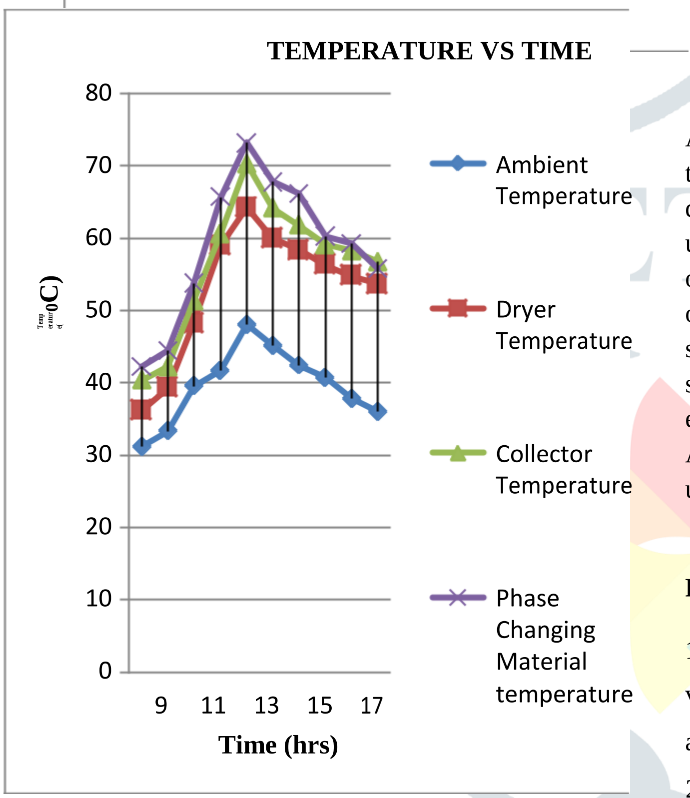
The Dryer is tested over a week (05/3/2019 to 12/3/2019) location at Sri Sairam engineering college, Mechanical department and the average values are graph below.











IX. ADVANTAGES

- Performances in both ON and OFF sun shine periods.
- The higher temperature, movement of the air and lower humidity increases the rate of drying.
- Food is enclosed in the dryer and therefore protected from dust, insects, birds and animals.
- The higher temperature deters insects and the faster drying rate reduces the risk of spoilage by microorganisms.
- The higher drying rate also gives a higher throughput of food and a smaller drying area (approximately one third).
- The dryers are waterproof; therefore, the food does not need to be moved during raining.
- Dryer can be constructed from locally available materials and are relatively low cost.

X.CONCLUSION

Agriculture is playing main role in India. In our 21st century there is wastage of agricultural product due to improper drying method. we introduce using a new designed solar dryer using renewable resource the sun for drying the products .In our improved design of solar dryer can dried product during on shine and off shine using Phase Change Material .The solar dryer is experimentally tested during on shine and off shine period of 10 hours over a day .For improving the efficiency we can use other Phase Change Material also. The Ambient temperature of air which is increased by 31% by using Solar Collector.

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