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An Experimental Investigation of a Biomass-Solar Integrated Dryer

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***Abstract*: After threshing, the moisture content of grains remains generally higher than the desired for safe storage of grains (13-14%). To attain safe moisture levels products are passed through post-harvest phase of drying. For safe storage and further processing moisture content is to be lowered by drying. Solar drying process by providing exposure to solar radiation may be disadvantageous e.g. exposure to direct sunlight, liability to pests and rodents lack of proper monitoring, and the escalated cost of the mechanical dryer, a hybrid dryer is therefore developed to cater for this limitation. This project focuses on development of a natural convection solar dryer combined with heat from burning of biomass. In the hybrid dryer, the heated air passes through a separate solar collector which consists of absorber plate and transparent cover to the drying chamber & solar collectors are reinforced with heat from burning biomass kept in a combustion chamber placed right below the drying chamber for raising the temperature inside it. The results obtained shows that the temperature inside the drying chamber is higher than the ambient temperature. Also comparing with natural convection solar dryer, the temperature obtained is higher.**

***Keywords*: Solar Energy, Biomass, Natural Convection Solar collector, Solar drier.**

1. Introduction

Preservation of agricultural produce is one of the central problems faced by developing countries. And as time goes on, these problems will be aggravated by the growing dietary needs of the ever increasing population of these countries.

A. Solar dryer

Solar dryers require a certain investment for the set-up of the appliance but no expenditures for the fuel. Basically a solar drier will heat air to some constant temperature with solar radiations, due to which humidity from crop get extracted within the drying chamber. Ventilation is enabled at a constant rate through defined air inlets and outlets, small solar ventilators or temperature difference, either due to exposition or vertical height.

B. Biomass for heat generation

A large number of small and medium industries, most of them for food processing and agricultural products, use biomass to generate and supply heat directly or through steam, hot water and hot air. The heat energy obtained from combustion of biomass can be used directly or supplied through carriers like steam and hot air. With the development of technology for drying of food and agricultural products supply of hot air at reasonable cost and controlled temperatures and in regulated quantity has become extremely important.

C. Problem statements

Net moisture content of air and its higher relative humidity hampers the efficient drying under the ambient conditions. The traditional open sun drying utilized widely by rural farmers has some noticeable limitations. For this to be feasible, the ambient relative humidity during the harvest period must be low enough to ensure that the crop, when dried to its equilibrium moisture content, can be stored safely. Meteorological data, even for the most favored areas, show that this is not always feasible.
Problems of farmers as identified in the study include:

- Poor storage capacity, leading to qualitative and quantitative losses and price fluctuations.
- Storage losses comprise of loss due to moisture, shrinkage, decay and sprouting.
- In case of glut in the market and with improper storage facilities, prices crash and sometimes the farmers are forced to destroy their crops.

D. Project objectives

The prime objectives of the project include:

i. To study different types of Solar Dryers.
ii. To develop a hybrid system for food drying so as to minimize the amount of food wastage because of moisture content present.
iii. Integrate non-conventional & biomass energy to improve the efficiency of solar dryers.

To overcome the problems associated with conventional solar dryers.

2. Design approach & methodology

A. Conceptual design of drying system

From the review of literature, it was found that a solar and biomass fired integrated drying system demands separate understanding and design for solar collector and biomass fired section. Accordingly, design works were carried out. The schematic of the conceptual design of solar-biomass integrated drying system is given in Fig. 1 and Fig. 2. The components of the drying system are solar collector; combustion chamber; hot air generation chamber; husk feeding assembly; flue gas chimney; drying chamber; drying trays.

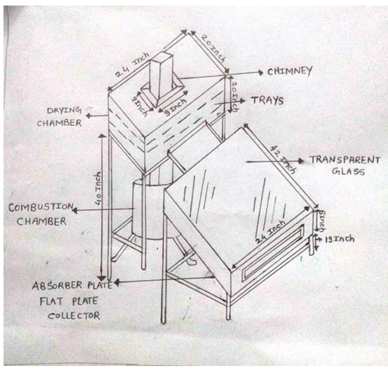

Fig. 1. Schematic of hybrid solar dryer

1) Collector (Air Heater)

The heat absorber (inner box) of the solar air heater was constructed using 5 mm thick Galvanized Iron (GI) plate, painted black, is mounted in an outer box built from GI Plate. The space between the inner box and outer box is filled with heatlon material of about 40 mm thickness and thermal conductivity of 0.043 $Wm^{-1}K^{-1}$. In a solar collector assembly air flow channel is provided which is enclosed by transparent cover (glazing) for incidence of sun light on the bottom surface of collector. The glazing is a single layer of 5 mm thick transparent glass sheet; it has a surface area of 610 mm by 1066 mm and of transmittance above 0.7 for wave lengths in the rage 0.2 – 2.0 μm and opaque to wave lengths greater than 4.5 μm. The effective area of the collector glazing is 0.6 m^2. One end of the solar collector has an air inlet vent of area 0.066 m^2.

2) The Drying Cabinet

The drying cabinet together with the structural frame of the dryer was built from Galvanized Iron which could withstand atmospheric attacks. An opening as outlet was provided toward the upper end at the back of the cabinet to provide and control the flow of air through the dryer due to convection. Door to access the drying chamber was also provided at the rear side of the cabinet. This consists of three removable trays made of 13 mm iron nets.

3) Drying trays

The drying trays are contained inside the drying chamber and were constructed from a wire mesh with a fairly open structure to allow drying air to pass through the food items.

4) Combustion chamber

A combustion chamber was conceived to have a horizontal grate for proper burning of solid fuel. A chimney on the exhaust side would create necessary draught for complete combustion and escape of flue gas. Cow dung was considered as fuel to generate required heat as a normal situation. The following assumptions were taken for functional design calculations:

Length of combustion chamber = 320 mm
Diameter of combustion chamber = 280 mm
Material of fabrication = Mild steel
Size of chimney = 0.01m2 (4 inches x 4 inches).

B. Mathematical Models and Formulations

1) Operation of the dryer

The dryer can be categorized as passive system as that it has no moving parts. Collector glazing allows sun rays to enter inside the system which provides it the required heat for operation. As the inside surface of the collector is black painted, there is increase in the trapping of rays, which heats the air inside the collector. The greenhouse effect achieved within the collector drives the air current through the drying chamber. If the vents are open, the hot air rises and escapes through the upper vent in the drying chamber while cooler air at ambient temperature enters through the lower vent in the collector. Hence, current of air maintained, as cooler air at a temperature T_a enters through the lower vents and air at a higher temperature T_e leaves through the upper vent. In addition to this another source of heat from burning of cow dung provides additional heat energy for increasing the temperature of drying chamber. If the drier is empty, as the temperature of air inside the drier is higher than the temperature of ambient air entering in it, air at the outlet vent is with lower relative humidity then the ambient incoming air rushing inside the drier which has higher relative humidity. Thus there is tendency for the out-going hot air to pick more moisture from the dryer as a result of the difference in relative humidity of ambient incoming air and hot outgoing air from the drier. Therefore, insulation received is basically used in increasing the affinity of the air in the dryer to collect moisture.

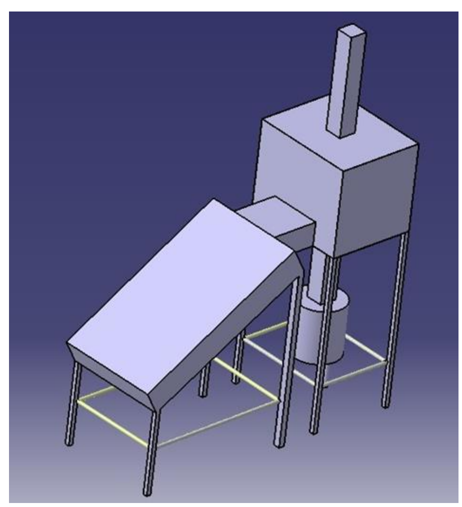

Fig. 2. CAD model of hybrid solar dryer

2) Drying mechanism

In the process of drying, heat is necessary to evaporate moisture from the material and a flow of air helps in carrying

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away the evaporated moisture. There are two basic mechanisms involved in the drying process:

The migration of moisture from the interior of an individual material to the surface. The evaporation of moisture from the surface to the surrounding air. The drying of a product is a complex heat and mass transfer process which depends on external variables such as temperature, humidity and velocity of the air stream and internal variables which depend on parameters like surface characteristics (rough or smooth surface), chemical composition (sugars, starches, etc.), physical structure (porosity, density, etc.), and size and shape of product.

C. Basic Theory (Formulations)

Some important formulae used are given as follows:

1) Determination of percentage moisture removed from the commodities

$$M.R = \frac{Mi - Mf}{Mi} * 100$$

Where,
M.R = % moisture Removed
M_i= initial mass of the sample
M_d= final mass of the sample.

2) Collector efficiency

$$\eta_c = \frac{Q\ (useful)}{Is * Ac}$$

Where,
Qu= mCpΔt
Ac = collector surface area
I_s = Solar Radiation.

3) Drying efficiency (η_d)

$$\eta_d = \frac{M.R * L}{Is * Ac}$$

Where,
M.R. = mass of moisture evaporated in one hour of drying.
L= latent heat of evaporation in the dryer temperature.

3. Design procedure & calculations

A. The Experimental Set-up


Fig. 3. Side View of the dryer

Hybrid solar dryer consists of an assembly of box-type absorber collector and biomass fired fuel burner using the materials that are easily obtainable from the local market. As shown in the Fig. 3, the dryer is consisting of the box-type absorber solar air collector, the drying chamber, combustion chamber, the drying trays and the chimney for exhaust.


Fig. 4. Box Type Solar Collector


Fig. 5. Drying Chamber


Fig. 6. Combustion Chamber

1) Collector (Solar Air Heater)

The heat absorber (inner box) of the solar air heater was constructed using 1 mm thick galvanized plate, painted black, the surface facing sunlight was painted with black paint containing (5%)black chromium powder to increase its absorbing capability. The solar collector was insulated with rock wool of about 5 cm thickness and thermal conductivity of 0.04 Wm^{-1} K^{-1} on all sides. The solar collector assembly consists of transparent cover (glazing) enclosing the air flow channel. In this work 4 mm thick single layered transparent glass sheet was used as glazing. It has a surface area of 0.82 by 1.20 cm and of transmittance above 0.86 (Fig. 5).

2) The Drying Cabinet and Drying Trays

The designing of the drying chamber depends on many factors such as the product to be dried, the required temperature and velocity of the air to dry food material, the quantity of the dried product and the relative humidity of the air passing over the food material. The drying chamber houses three drying racks, distance between a tray and another tray is 15 cm, Three trays of dimension (0.6 x 0.48x 0.08 m) were fabricated and stacked uniformly/evenly at distances (0.08 m) apart, for placing of material to be dried. The tray was made from an iron wire mesh (0.003 x 0.003 m in size) attached to it.

4. Result & discussions

After carrying out series of experimentations with the hybrid solar dryer shown significant rise in temperature inside drying chamber. In the time span of 4 hours, it was found that the temperature in drying cabinet is in the range of 57ºC to 82ºC which is found to be significantly more than Conventional Solar Dryer which can attain maximum temperature of only 67º C.

The results obtained from the experimentation are represented graphically:

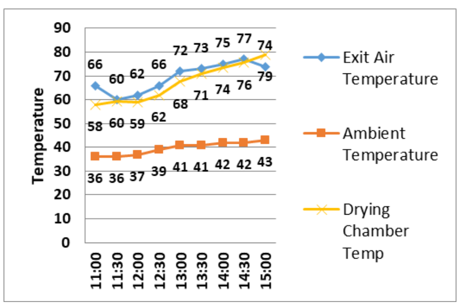

Fig. 7. A typical day results of the diurnal variation of temperatures in the solar dryer

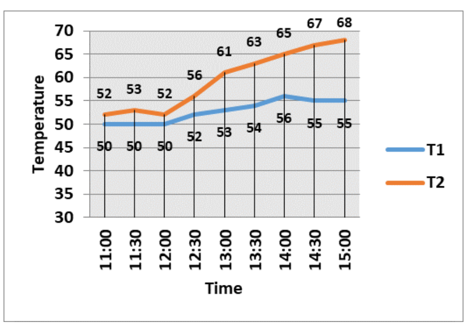

Fig. 8. Inlet & outlet temperature of solar collector

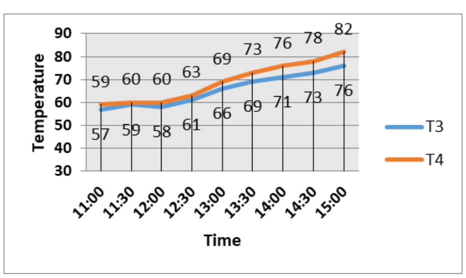

Fig. 9. Tray 1 & Tray 2 Temperature

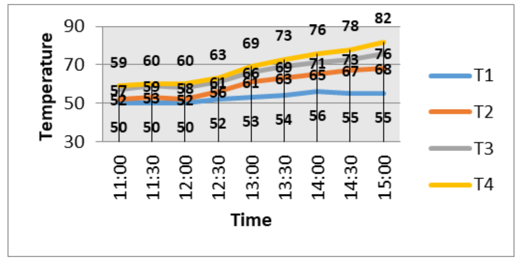

Fig. 10. Graph showing temperatures in solar collector, drying trays & chimney.

5. Conclusion

1. Effect of density difference of hot air is observed, due which temperature in the topmost portion of dryer compartment and above top of third tray is always observed higher.
2. Use of combustion chamber fired with biomass and chimney carrying hot flue gases contribute to rise in temperature in the dryer compartment.

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