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Design and Development of Solar Crop Dryer Integrated with Oil Bath

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ABSTRACT

This work presents the design and development of solar crop dryer with drained SAE 20/40 from vehicles oil as heat storage material. The details design, fabrication and experimental analysis procedure of the developed dryer are explained. The crops used during the experiments were potato slices (2 kg) and ginger (2 Kg) while air velocity maintained at 10 m/s. Potato slices of upper and lower trays have taken the drying time of 5 hours and 6 hour to reach safe storage moisture content of below 15 % and whereas ginger of upper tray and lower tray have taken drying time of 9 and 10 hours to reach moisture content of below 15. The maximum value of instantaneous of the collector (Oil bath) efficiency reported was 57. 48 % and minimum value was 18.59 %.

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INTRODUCTION

The world's requirement of food products has been increasing due to population explosion and the people's change in eating habits. Therefore, to meet the food products requirement of the world's population is a major challenge. In developed countries, advanced technologies are adopted in production and storage of food product, whereas in developing countries due to lack of modern technologies in the field of food products production and storage, providing food security is a major problem and it is an immediate requirement to develop low cost techniques to increase the food production rate, reduce the harvesting losses and to minimise storage losses. *Food and Agricultural Organisation of United States* estimated that, loss of post harvesting food products is high in developing countries and yearly food loss by quantity estimated is around 30 percent of cereals, 40 –50 percent of root crops, fruits and vegetables, 20 percent of oilseeds, meat and dairy products, and 35 percent of fish [1]. To produce food products, it is required to consume resources like fresh water, agricultural land, fertiliser, pesticides, human work and mechanical energy. Therefore, loss of food products affects the waste of all these resources [2]. If technologies are developed to reduce the loss of food products, it indirectly saves other resources and helps to achieve food security. Solar drying is one of the applications of solar energy that can be used to reduce loss of food products. Solar drying is a simple method and sun's energy is available at free of cost. Therefore, solar drying is the best suitable for developing countries, where sufficient cold storage facilities are not available for food products storage. Common crop drying method practised from ancient time is by spreading product to be dried over a platform or plane surface and product is directly exposed to the rays of sun, moisture evaporation takes place due to heat of sun's rays and due to flow of atmospheric air over the product surface. This method of drying is called as open sun drying or natural drying. The open sun drying is a simple and economical method but it suffers from lot of disadvantages like no control over the drying rate, attack by birds and animals, dust and other particles may mix with the product, sudden rain may cause damage [3] and long drying time of a crop with direct ultraviolet light may degrade valuable photochemical [4]. To overcome the disadvantages of open sun drying, solar dryers are developed. Solar dryers are mainly three type's namely direct mode solar dryers, indirect mode solar dryers and mixed mode solar dryers. In direct mode solar dryers, solar radiation is allowed directly to incident on the product to be dried whereas in indirect mode dryers, air is heated by a solar collector (air

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heater) and then allowed flow through a closed drying chamber and mixed mode dryers employs the features of both direct mode and indirect mode dryers. Food crops are diversified in their properties, so selection of dryer depends on the different parameters, like physical features of dryer, thermal performance, being handled, drying characteristics of the material, flow of material to and from the dryer, product qualities, facilities available at site of proposed installation and economics

People of technical and scientific community around the world have developed different types of solar crop dryers. Prior to design of any dryer, it is very essential to understand the drying phenomenon of crops under open sun drying conditions, Jain and Thiwari [5] studied and discussed many thermal aspects of open sun drying of various crops like green chillies, green pea, onions, potatoes, and cauliflower and it reported that, the convective heat transfer coefficient for varied significantly with type of crop. This is mainly due to porosity, shape, size and initial moisture contents of the crops are different. Therefore, process of drying characteristic is not the same for all crops and it is depending on properties of crop. Construction of solar dryers is an easy process, because most of crops not demands higher temperature and for a instance preferred drying temperature for Corn is 68 - 80 ^{0}C, Bananas is 70 ^{0} C. Researcher [6] designed a solar grain dryer for domestic applications by using locally available materials such as, plywood, perplex glass, wire mesh angle iron and similar type of simple direct mode dryers were also invented for drying of yam crop [7], fishery products [8] and tropical crops [9].

For photosensitive crops, it is not desirable to expose crop directly to Sun's rays because direct explosion causes loss of nutritious contents from the crops and for photosensitive crops indirect mode dryers are the best suitable approach. Researchers have developed indirect mode drying systems by using different materials to collect solar energy to heat the incoming atmospheric air. Some of the important materials used were gravels for chillies drying [10], vacuum tube collectors were used for drying of chillies [11], sand bed was also used to collect heat energy from the sun [12] and phase change materials were also reported for drying grapes [13].

As mentioned in the earlier section, mixed mode dryers employs the principle of both direct and indirect modes of dryers and it is observed in the literature that, researchers around the world have proposed their concepts mixed mode dryers for crop drying. A mixed mode dryer for drying of Yam's chips have been developed by using 2 mm aluminium sheet for absorber material and well seasoned wood for cabin material [14]. Similar dryer type of dryer with iron sheet as the absorber material was proposed for the drying of Cuminum grains [15]. Some researchers were tried to improve the performance of dryers by using simple techniques like pebbles (heat storage material) coated with black [16]. Recent mixed mode solar crop dryers developed with sensible heat storage materials are; pebbles as heat storage material for drying of chillies [17], pebbles with black coating for drying of chillies [18].

Apart from the conventional research work on dryers some typical category of dryers were also developed and one such dryer developed was cylindrical glass drying section chamber developed and a flat plate collector (Air heater) made of galvanised steel sheet as absorber) was used [19]. The advantage is cylindrical glass drying chamber receives sun's rays from all the directions without any tracking mechanism. Mathematical and numerical model analysis to understand drying phenomenon were also carried out for the drying models of cylindrical tunnel type [20], direct mode, indirect mode and mixed mode type of dryers [21].

In this work a mixed mode solar crop dryer was designed for agricultural crop drying. Used SAE 20/40 lubricating oil from the automobiles was used to collect solar energy by means of oil bath**.**

MATERIAL AND METHOD

Selection of oil for heat storage

Large quantity of lubricating oil is used in the vehicles to reduce the friction between the moving parts. Lubricating oil absorbs heat released due to friction between moving parts and lubricating oil produces a thin oil film between the moving parts. Lubricating oil loses its properties during the engine operation over a period of time and then it is replaced by new engine oil. It is observed that in many local small vehicle service stations during the process of refilling, the drained lubricating oil from engines is not collected properly and it is not sending to recycling process. The common method practiced in local vehicles service stations to dispose the drained engine oil is by direct burning, this is a waste valuable resource. This wastage can be reduced by incorporating with solar dryers, because the solar dryers are decentralised type of systems and can be used wherever sun's energy is available.

The drained SAE 20/40 engine oil from a local vehicle service station was collected and flash and fire points were found by using Cleveland open cup apparatus. The flash fire point for fresh SAE 20/40 oil was observed at 224 ^{0}C and 245 ^{0}C whereas for the drained SAE 20/40 oil the flash point was 120 ^{0}C and the fire point was 140 ^{0}C. It is observed that, the flash and fire points of used lubricating oil drops down, this is because during the engine operation the lubricating oil is subjected to repeated heating and cooling and this leads to weaken the chemical bonds and therefore oil loses its property to form a thin film between moving parts.

Higher drying temperature is not preferable for crop drying, because crop loses germinating property at higher temperatures and possibility of losing some important nutrients. For most of the crops, drying temperature required is not high temperature and it is in the ranges from 40^0 C to 80^0 C. The required moderate temperature of crop drying is achievable by economically available sensible heat storage materials. In this work an attempt is made to use drained engine oil for solar drying applications.

Design and fabrication of experimental setup

As earlier quoted in the introduction part, selection of dryer is bound by number of parameters and accurate design procedures have been not developed. In this work the drying chamber and heat storage material (Oil bath) casing dimensions were selected by keeping length to width ratio as 1.5, length and width of both heat storage casing and dryer dimensions were maintained identical [22]. This dryer has been developed to remove the moisture from crops in all seasons and therefore annual optimisation of slope have been followed i.e. slope is equal to latitude of the test location [23].

The complete experimental setup was fabricated by using low cost materials available at local market, galvanised iron sheet of 0.5 mm thickness is used to develop oil bath and drying chambers and transparent glass cover of 5 mm thickness is used to reduce reradiating losses and to maximise the rate solar energy collection, inside exposed surfaces of both the chambers are coated with black. Insulation at all sides of both the chambers is provided with thermo-coil. A spiral aluminium tube is immersed in the oil bath and inlet is connected with air blower and outlet is connected to a drying chamber. At the top, ventilating facility had provided. Two Iron mesh trays were used to keep the products to be dried. The care had taken for air gaps and other leakages. The complete experimental setup is fixed towards south direction. India is located in northern hemisphere of the earth. The sun in winter rises in south east and sets in south west. The collector for all locations in India should be oriented in a direction facing south [24], therefore the fabricated experimental setup was fixed towards south direction. The schematic diagram of experimental setup and pictorial views ares shown in Figures 1 and 2, respectively.

Preliminary experiments on oil bath chamber were conducted to find optimum air velocity and In equation (1), m_a is mass flow rate of air in kg/s, C_p is specific heat of air in J/kgK, T_1 and T_2 are air inlet and outlet temperatures in ^{0} C, I_c intensity of solar radiation in W/m^2, A is gross area of heat storage cabin in m^2 and W_P is power required for blower. The optimum oil depth, the optimum velocity obtained was 10 m/s and optimum oil bath depth was 60 mm.

Experimental procedure

Products used during the experiments were potato slices and

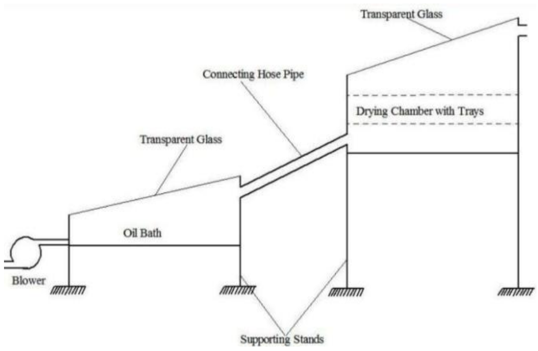

Figure 1. Shematic diagram of expermental setup

Figure 2. Pictorial diagram of experimental setup

ginger. In the first set of experiments, 4 kg of potatoes slices were placed on two trays of the dryer and experiments were started at 9:00 am and stopped when the potato slices reached to safe moisture content level and the same procedure was repeated for drying of ginger. The maximum percentage of moisture content for safe storage recommended is below 20 percent for fruits, below 10 percent for vegetables and 10 to 15 percent for grains [25]. Potato slices and ginger were used in this study and they are vegetables, so below 15 percentage of moisture content was taken safe moisture content during the experiments. For every one-hour interval steady state readings were taken, calibrated digital weighing machine was used to measure weight of the product, calibrated thermometers were used to measure temperate at different locations of the experimental setup and pyrometer was used to measure intensity of solar radiation.

Performance analysis

Determination of overall thermal efficiency of the dryer

To find the thermal efficiency of solar collectors two methods are used; the instantaneous method and the calorimetric method. For testing of solar collectors, instantaneous method is widely used [26]. The equation (1) represents the thermal efficiency of solar collector by instantaneous method.

$$\eta_H = \frac{ma\ Cp\ (T2-T1)}{Ic\ A+WP} \tag{1}$$

In equation (1), m_a is mass flow rate of air in kg/s, C_p is specific heat of air in J/kgK, T_1 and T_2 are air inlet and outlet temperatures in ^{0} C, I_c intensity of solar radiation in W/m^2, A is gross area of heat storage cabin in m^2 and W_P is power required for blower.

Determination Moisture Content

To find the moisture content of a product two methods are used, wet basis method and dry basis method. Most of the researchers have been used wet basis method. The equation (2) gives correlation to calculate moisture content based on wet basis.

$$M_{WB} = \frac{(W - Wd)}{W} \times 100 \tag{2}$$

In equation (2), W_{WB} is moisture content, W is weight at any given drying period and W_d is dry bone weight. Electric oven method is used to find dry bone weight of the product.

Determination of Drying Rate

Drying rate is the amount of moisture evaporated from a product for given drying time. Equation (3) represents the rate of moisture evaporated

$$DR = \frac{dm}{dt} \tag{3}$$

In equation (3), dm is difference in weight and dt is time period.

Determination of Heat Energy Used

The heat energy used to evaporate the moisture from a product is calculated by using equation (4)

$$Q = (W_0 - W)\ h_{fg} \tag{4}$$

In equation (4) W_0 is initial weight of the product, W is the final weight of the product and h_{fg} is latent heat of vaporization of water.

Determination of Relative Humidity (Φ) Relative humidity is the ratio the mass of water vapour to the mass of saturated water vapour in the same volume at the same temperature. The correlations (5) and (6) are used to find the relative humidity.

$$Pv = (Pvs)_{WBT} - \frac{(P-(Pvs)WBT)-(DBT-WBT)}{1427-1.44\ WBT} \tag{5}$$

$$\Phi = \frac{Pv}{PVS} \tag{6}$$

RESULTS AND DISCUSSIONS

In this section obtained results are discussed with the help of performance curves drawn. The Figure 3 represents the performance curve of drying time weight of the product. It is observed that, the product of upper trays looses the more amount of water content than the products of lower trays. This is because, products of upper tray receive direct sun's radiation and on the products of lower trays, shading effect of upper trays is always present and this shading effect causes to receive less amount of sun's heat for moisture evaporation. Figure 4 represents the drying time against percentage of moisture content of the product on wet basis. As mentioned in the section 2.1 for vegetables and fruits recommended moisture content of the product is below 15 percent. Moisture present in the vegetables and fruits is of two types; bound moisture and unbound moisture. Bound moisture of the product is not possible to remove because of cells arrangement and unbound moisture is possible to separate from the product during the drying process. The potato slices have the initial moisture content of 78.5 % and ginger has 78 %. In the initial drying time between 9 to 10 hours, both potato slices and ginger have shown almost equal percentage of decrease in their moisture content and after this duration deviation in the percentage of moisture decrease was observed and this is due to fact that, during the period of initial drying more amount of moisture is available in the product at outer surfaces and therefore percentage of moisture decrease is almost the same for both potato slices and ginger. As the drying process progresses, the percentage of moisture content decreased is high for potato slices than the ginger. In the potato slices the surface structure is made of less number of fibres whereas in the ginger surface structure is made of more number of small fibres and this structure causes obstacle to the water to flow from inner surfaces to the outer surfaces to get evaporated. Therefore, structure of the material plays an important role in the drying process. The potato slices at upper trays requires a drying time of 5 hours to reach safe storage moisture content, potato slices at lower tray requires 6 hours drying time to attain safe storage moisture content. The ginger at upper tray takes 9 hours of drying and ginger at lower tray takes 10 hours of drying to reach the safe moisture content. The moisture evaporation for a given time period is called drying rate.

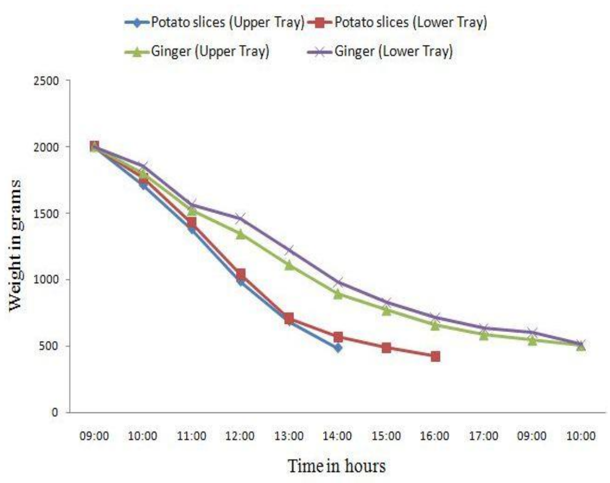

Figure 3. Drying time V/S Product weight

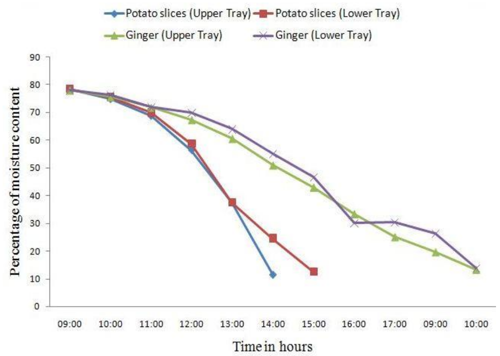

Figure 4. Drying time v/s Percentage of moisture content

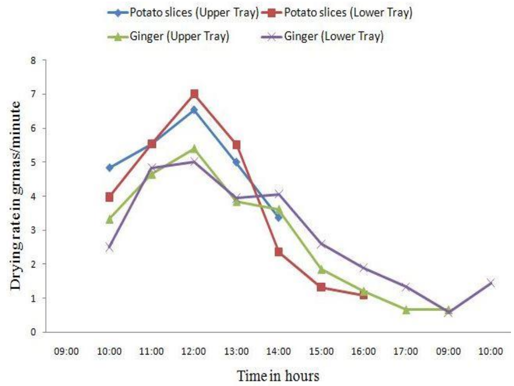

Figure 5. Drying time v/s Drying rate

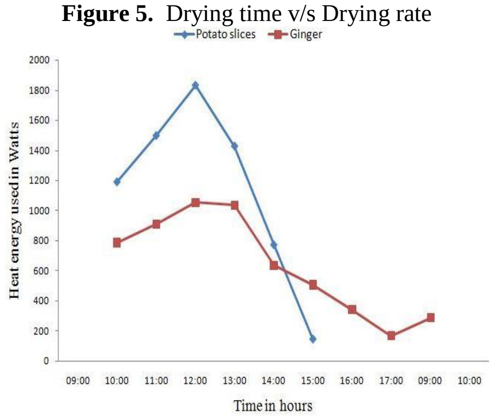

Figure 6. Drying time v/s Heat energy used

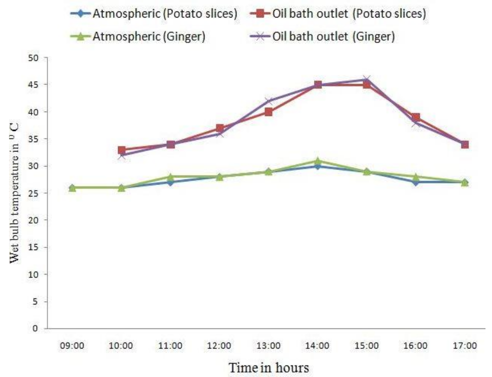

Figure 7. Drying time V/S Wet bulb temperature

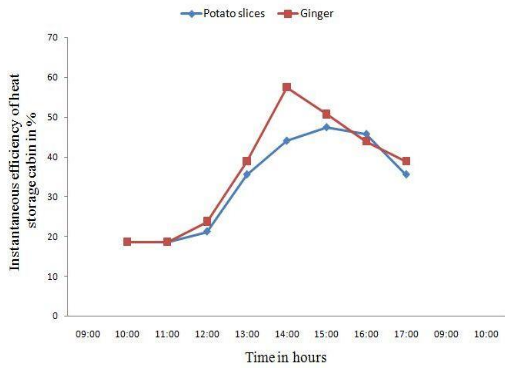

Figure 8. Drying time V/S Instanatneous effiency of the heat storage cabin

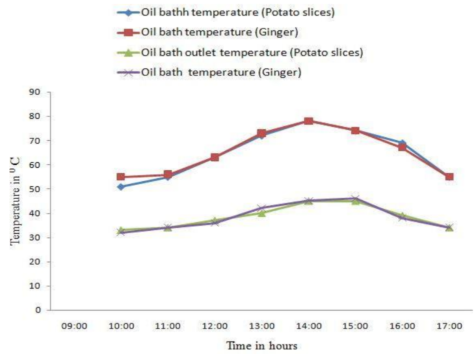

Figure 9. Drying temperature V/S Temperature

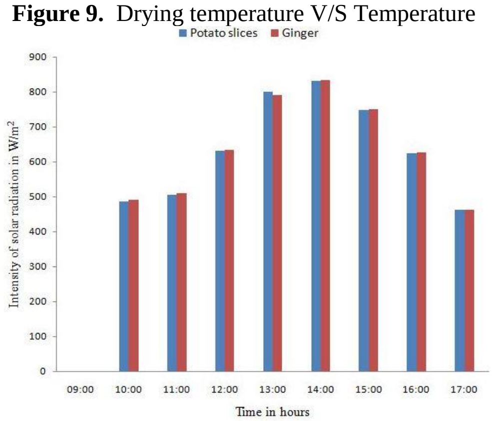

Figure 10. Drying time V/S Intensity of solar radiation

Figure 5 represents curves of drying time against drying rate and it was observed that, during the initial periods drying the drying rate linearly increased with drying time and attained a maximum drying rate. The maximum drying rates observed for potato slices is 6.99 g/min (Upper tray) and 6.5 g/min (Lower tray), similarly for ginger maximum drying reported were 3.8 g/min (Upper tray) and 4.08 g/min (Lower tray). During the periods of initial drying, more amount of water is available at outer surfaces. Therefore, drying rates increases linearly with drying time and after reaching maximum value of drying rate, the amount of water present in the product is less. In addition, drying rate decreases sharply and at the end periods of drying the products contains less amount of unbound moisture. Therefore, drying rate is becomes almost constant. The heat energy of sun's radiation is a main reason to evaporate moisture from the product, so more amount of moisture is possible to be removed from the products if the rate of heat transfer to the product is high. It is observed from Figure 6 that, the rate of heat energy used for drying of potato slices is more as compared the rate of heat energy used for ginger drying. This is because, potato slices having large surface area for heat transfer whereas the surface area available for heat transfer is comparatively less in ginger drying. Figure 7 represents the variation of wet bulb temperature (WBT) with drying time. It was observed that, atmospheric air WBT was significantly increased after passing through oil bath and an increase in WBT decreases the relative humidity of the air and thus water carrying capacity of air increases. The variation of atmospheric WBT and oil bath outlet WBT is almost same and this results in more accuracy in the analysis. The variation in the instantaneous efficiency of heat storage cabin is shown in Figure 8. The nature variation in the efficiency is same during the drying potato slices and ginger. During the initial periods, efficiency is the same and after the initial period, efficiency increases and reached to maximum value and start to decrease. The maximum efficiency reported is 57. 48 % and minimum is 18.59 %. The variation of oil bath temperature and outlet air temperature of oil bath is given in Figure 9. The temperature of oil bath is always at higher temperature than the outlet air temperature of air from the oil bath. The tube used during the experiment was aluminium tube and practically for any system it is not possible to transfer heat completely. The rate heat transfer can be increased by using the tube which is having better thermal conductivity, but tubes with high thermal conductivity are costly and this increases the total cost of the system. The efficiency of oil bath is influenced by amount of sun's radiation available. A day with good sunshine hours helps to get better efficiency. The maximum oil bath temperature reported is 78 ^{0}C and minimum temperature is 51 ^{0}C and at the outlet of oil bath the maximum and minimum air temperature reported is 66 ^{0}C and 41 ^{0}C. The required amount of heat energy for product drying is by sun's radiation and intensity of incident solar radiation affects on the process of drying. In a day with sky free from clouds receives high rate of sun's energy as compared to a day with clouds. During the experiments sky was free from clouds and the maximum amount of radiation had received. Figure 10 shows the variation in solar radiation intensity with drying time. It is observed that, the received amounts of solar radiation during the experimental time are very close to each other and hence uncertainty is not considered for the analysis. The maximum value of solar radiation received is 833 W/m^2 and minimum is 463 W/m^2.

CONCLUSIONS

The present work explains the design, fabrication and experimental analysis of a solar drying system integrated with oil bath. The substance used for collecting heat was used SAE 20/30 engine oil. The food products used during the experiments were potato slices and ginger. The use oil bath enables to collect solar energy in the form of heat and helps to avoid sudden variation in the dryer temperature due environmental interruptions. Potato slices of upper and lower tray have taken the drying time of 5 and 6 hours to reach safe storage moisture content of below 15 % and whereas ginger of upper tray and lower tray have taken drying time of 9 and 10 hours to reach moisture content of below 15 %. The internal structure of material affects on process of moisture evaporation during the drying process. Products with internal structure with less number of fibres shows better drying rates as compared to product with internal structure made of large numbers of fibre. The surface area of product which is exposed to the current of hot air stream affects on the process of drying. The maximum value of instantaneous efficiency reported was 57. 48 % and minimum value was 18.59 %.

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Persian Abstract

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چکیده

این کار طراحی و توسعه خشک کن خورشیدی را با تخلیه SAE 20/40 از روغن خودرو به عنوان مواد ذخیره سازی گرم ارائه می دهد. طراحی، ساخت و روش تجزیه و تحلیل جزئیات خشک کن توسعه یافته توضیح داده شده است. محصولاتی که در طول آزمایش استفاده می شود، برش های سیب زمینی (۲ کیلوگرم) و زنجبیل (۲ کیلوگرم) بود در حالیکه سرعت هوای ۱۰ متر در ثانیه حفظ شد. تکه های سیب زمینی سینی های بالایی و پایین تر زمان خشک شدن ۵ ساعت و ۶ ساعت را برای رسیدن به رطوبت ذخیره سازی زیر ۱۵ درصد حفظ کرده اند و در حالی که زنجبیل سینی فوقانی و سینی پایین تر از زمان خشک شدن ۹ و ۱۰ ساعت برای رسیدن به رطوبت کمتر از ۱۵ است. حداکثر مقدار لحظه ای از کارایی کلکتور (روغن حمام) گزارش شده است ۵۷. ۴۸٪ و حداقل مقدار به ترتیب ۱۸،۵۹٪ می باشد.