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ABSTRACT
Drying is a very important process applicable to agricultural products. It is the moisture removing the process from the products. Drying reduces the bacterial growth in the products. It will helpful for preserving the products for a long time. Open air solar drying method is used frequently to dry the agricultural products. This method has many disadvantages such as spoil products due to rain, wind, dust, insect infestation, animal attack and fungi. Foods should be dried rapidly, but the speed of drying will cause the outside becomes hard before the moisture inside has a chance to evaporate and it will affect the quality of the dried product due to over-drying. Therefore to avoid disadvantages it is necessary to use the other solar drying methods. Many types of the solar dryer are available in the market but its cost is not economical for rural peoples and electricity is needed to operate the fans of a forced convection solar dryer. However, many rural areas either have no electricity or have to incur high costs to generate the electricity used to run this type of dryer. The use of solar dryer is limited because of drying is not possible due to frequent clouds in the day or the evening. Therefore, these types of dryers are not widely applicable in many developing countries. To avoid the above-mentioned disadvantages, a natural convection solar dryer may be used. This type of dryer is not dependent on electricity. Its advantages include low cost, ideal shrinkage in the drying period, better drying capacity, minimization of mass losses, and good quality of the dried products. In this Research, based on preliminary investigations an indirect, Passive-type, environmentally friendly, low-cost solar dryer integrated with sensible heat storing material is designed to dry various agricultural products. The dryer has been fabricated by locally available, biologically degradable, low-cost materials. The dryer consists of a solar flat plate air heater with insulation, drying chamber designed to induce a required air flow in the system. A potato has been chosen for the experimentation since it is high in production and also has a substantial loss. The experiments will be conducted to dry the products and measure the ambient temperature and temperature inside the dryer as well as solid moisture loss-in-weight data are employed to analyze the performance of the dryer.

Keywords: Passive Solar Dryer, Solar Dryer with Heat storage Materials, Economical Solar Dryer.

1. INTRODUCTION
In many parts of the world, awareness is growing about renewable energy which has an important role to play in extending technology to the farmer in developing countries like Ethiopia to increase their productivity. Poor infra-structure for storage, processing and marketing in many countries of the Asia-Pacific region results to a high proportion of waste, which average between 10 and 40 % [1]. Although India is a major producer of horticultural crops, many peoples in the world are unable to obtain their daily requirement of fruits and vegetables and the Human Development Index (HDI) is very low. Considerable quantities of fruits and vegetables produced in world go to waste owing to improper postharvest operations and the lack of processing. This results in a considerable gap between gross food production and net availability [1]. Reduction of postharvest losses is essential in increasing food availability from existing production [2]. Traditional techniques used in food preservation are drying, refrigeration, freezing, salting (curing), sugaring, smoking, pickling, canning and bottling. Among these, drying is especially suited for developing countries with poorly established low-temperature and thermal processing facilities. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply.
Drying is a method of dehydration of food products which means reducing the moisture content from the food to improve its shelf life by preventing bacterial growth [3]. It is still used in domestic up to small commercial size drying of crops, agricultural products and foodstuff such as fruits, vegetables, aromatic herbs, wood etc. contributing thus significantly to the economy of small agricultural communities and farms [4]. The use of drying technologies product quality can be improved and product losses can be reduced. Solar drying is the best alternative that can help improve the quality of products [5]. One example is presented by Barnwal and Tiwari who developed a photovoltaic (PV) green-house thermal dryer for seedless grapes. In their system, they calculated the evaporation of moisture, surrounding grape temperature, ambient air humidity, and greenhouse temperature to examine heat and mass transfer. They obtained satisfactory results [6].

Studies have shown that commercially available dryers are not applicable for the most farmers, due to lack of capital and insufficient supply of energy for the operation. The high temperature dryers used in industrialized countries are found to be economically viable in developing countries only on large plantations or big commercial establishments. High initial investment for solar dryers still remains a barrier to a wide application. Therefore the introduction of low cost and locally manufactured solar dryers offers a promising alternative to reduce the tremendous post-harvest losses. The opportunity to produce high quality marketable products seems to be a chance to improve the economic situation of the farmers.

Preservation of agricultural products is essential for keeping them for a long time without further deterioration in the quality of the product. Several process technologies have been employed on an industrial scale to preserve food products, among that. Drying is the efficient and reliable method. It offers a highly effective and practical means of preservation to reduce postharvest losses and offset the shortages in supply. Drying is a simple process of moisture removal from a product in order to reach the desired moisture content and is an energy intensive operation. The prime objective of drying apart from extended storage life can also be quality enhancement, ease of handling, further processing and sanitation and is probably the oldest method of food preservation practiced by humankind.

Drying is a method of dehydration of food products which means reducing the moisture content from the food to improve its shelf life by preventing bacterial growth [7]. Drying process takes place in two stages first one happens at the surface of the drying material at constant drying rate and is similar to the vaporization of water into the ambient and second stage is according to properties of drying product with decreasing drying rate [8].

Dryers have been developed and used to dry agricultural products. Most of these require more capital investment and use an expensive source of energy such as electricity. The uses of solar dryers have not been adopted by the small farmers because the cost has remained inaccessible and the subsequent transfer of technology. The low cost and natural convection dryer will be designed and fabricated and its efficiency will be analyzed. The use of solar dryer is limited because of drying is not possible due to frequent clouds in the day or in the evening. If storage of solar energy can provide in solar dryer, then there is the possibilities of drying product in evening time. Hence the energy can be stored either in sensible or latent heat storing materials. An indirect passive solar drier integrated with sensible heat storage material has been developed for recovering this limitation. Gravel is one of the good sensible heat storage materials [7] and it will be used for packing material. Experimental will be conducted to identify its performance for various agricultural products. The general objective of this research is to Design and Fabricate the passive solar dryer and to Integrate gravel as the energy storage material.

2. LITERATURE REVIEW

Hii et al. have shown that sun drying is economical, but the product obtained by it is of lower quality due to contamination by dust, insects, birds, pets and rain. Also, loss of vitamins, nutrients and unacceptable colour changes due to direct exposure to ultraviolet rays[8]. Umogbai et al. made a comparison between sun drying and solar drying and obtained that solar dryers generate higher temperatures, lower relative humidity, lower product moisture content and reduced spoilage during the drying process than sun drying [9]. Rajeshwari and Ramalingam have demonstrated that the drying time in case of solar dryers compared to open air drying reduced by about 20 % and produces better quality dried products [10]. Gornicki et al shows by studying of the orange-fleshed sweet potato with different pretreatment and by testing vitamin degradation in the same product dried in three different dryers. The reason for this could be the great variation in size and shape of the pieces, different pretreatment, temperature, time, exposure to light and oxygen[11].

Yusuf Abdullahi et al designed a model of a box type adjustable and collapsible natural convection solar food dryer, capable of drying 16.52kg of fresh groundnut with maximum moisture content of 35%, was designed and constructed using locally available materials.[12] R. VidyasaGarRaju et al constructed laboratory dryer based on preliminary investigations of drying under controlled conditions. The designed dryer with a collector area of 1m² is expected to dry 20kg fresh vegetables from 89.6% to 13% wet basis in two days under ambient conditions during harvesting period from February to March[13]. Diemuodeke et al experimented the direct natural convection solar dryer was designed and fabricated to dry tapioca in the rural area[14].
A. Madhlopa et al. developed an indirect type natural convection solar dryer integrated with collector storage and biomass-backup heaters. The major components of the dryer were biomass burner (with a rectangular duct and flue gas chimney), collector-storage thermal mass and drying chamber[15]. A.A. El-Sebaii designed an indirect type natural convection solar dryer. The system consists of a flat plate solar air heater connected to a cabinet acting as a drying chamber[16]. I.N. Simate developed a comparison of optimized mixed-mode and indirect-mode natural convection solar dryers for drying maize. The models are run under variable solar conditions in order to optimize the dryers and compare their performance[17]. A. Balasudhakar et al. reviewed the various passive solar dryers for agricultural products[18]. It has been identified from the review of literature that the passive solar dryer has not been designed with energy storing material. In the present research, low-cost indirect-type solar dryer will be fabricated with gravel as an energy storing material. The performance of the dryer has been measured in the form of moisture removal rate and dryer efficiency.

3. MATERIALS AND METHODS

3.1. Materials

The following Materials have been used in this research. All the materials are low cost and locally available.

1. Wood
2. Plywood 18mm thick
3. Galvanised Aluminium sheet 2mm thick
4. Glass 2mm thick
5. Stainless steel Net 2mm thick
6. Gravel
7. Wire Mesh

3.2. Research Design

The collector consists of the solar absorbing plate, which is made of galvanized Iron sheet 2 mm thick 964 mm long and 464 mm wide. The collector casing is made of wood to prevent escape of heat. The top of the collector is made of one layer of 2mm thickness of colourless glass sheet 500 mm long and 500 mm wide, which is more efficient than other materials. A gap of 200 mm between the glass cover and the absorber plate forms the air passage. The gravels will be filled below the absorber plate of 40 mm thickness. The drying chamber is the place where the drying function takes place. The access door for loading and unloading of the products is positioned at the side of the drying chamber to reduce shadow during handling. The storage unit is matched with the drying chamber and occupying a volume of 424 x 424 x 464 mm. There are two air vents generally referred to as inlet air vent and outlet air vent. The air intake into the collector is through a 300 x 50 mm slot made through the collector wooden casing between the absorber plate and the bottom of the collector, which forms the airflow duct. The outlet air vent is situated at back side of the drying chamber.

The drying chamber and solar collector stands constitute the dryer stands. Dire dawa, lies at latitude 9°6’ N, longitude 41° 86’ E. The collector slope of (9+15)/24° which is an approximation of the latitude was used in the design. The solar collector was therefore mounted on a stand fabricated from a hard wood inclined at 9° to the horizontal south facing. Since the entire load is expected to come from the collector during sunshine on daytime operations and since the design is for all-year applications.

\[
\text{Depth of collector}= \frac{L_c}{d_c} = 5 \text{-------------------------(1) [15]} \\
L_c=1000\text{mm} \\
d_c=200\text{mm} \\
\text{Tilting angle of Solar Collector = Latitude} + 15°=24° \text{-(2) [15]} \\
\text{Where,} \quad L_c, d_c – \text{Length and depth of collector}
\]
3.3. Working Mechanism

The heat absorber of the solar air heater was constructed using 2 mm thick Iron plate, painted black, is mounted in an outer box built from plywood. The solar collector assembly consists of air flow channel enclosed by transparent glass. An absorber mesh screen midway between the glass cover and the absorber back plate provides effective air heating because solar radiation that passes through the transparent cover is then absorbed by both the mesh and back-plate. The glazing is a single layer of 2 mm thick transparent glass sheet; it has a surface area of 0.4473 m². One end of the solar collector has an air inlet vent of area 0.0125 m².

The collector plate is always tilted and oriented in such a way that it receives maximum solar radiation during the desired season of used. The best stationary orientation is due south in the northern hemisphere and due north in southern hemisphere. Therefore, solar collector in this work is oriented facing south and tilted at 24° to the horizontal. This inclination is also to allow easy run off of water and enhance air circulation. The drying chamber together with the structural frame of the dryer was built from plywood. An outlet vent was provided toward the upper end at the back of the cabinet to facilitate and control the convection flow of air through the dryer. Access door to the drying chamber was also provided at the front of the cabinet. This consists of wooden panels made of 18 mm plywood, which overlapped each other to prevent air leakages when closed. The inside of chamber area is covered
by aluminium foils to reduce leakage of heat. The drying trays are contained inside the drying chamber and were constructed from a fine wire mesh with a fairly open structure to allow drying air to pass through the food item. The dryer is a passive system in the sense that it has no moving parts. It is energized by the sun’s rays entering through the collector glazing. The trapping of the rays is enhanced by the inside surfaces of the collector that were painted black and the trapped energy heats the air inside the collector. The hot air rises and escapes through the upper vent in the drying chamber while passing the chamber hot air absorbs the moisture content from the drying item.

4. PERFORMANCE EVALUATION

The solar dryer will be placed under the sun light location. The experiments has been conducted in daily 9 am to 5 pm for finding efficiency of heater and 5 pm to 7 pm for finding energy storing capacity. Slice potatoes have been chosen for samples. The Thermometer was used for the measurement of temperature in the dryer. The temperature was measured for each hour from 9 am to 5 pm at two points namely Ambient air Temperature and outlet Temperature of drying chamber. The weight of the vegetables measured using a digital weighing pan. All the experiments were repeated to confirm the repeatability of the data obtained.

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\text{Moisture Loss} = \frac{M_i - M_f}{M_i} \quad \text{(3)} \quad [14]
\]

\[
\text{Percentage of Moisture Removed} = \frac{M_i - M_f}{M_i} \times 100 \quad \text{(4)} \quad [14]
\]

Where,

- Mt, Md-Initial and final mass of the product
- Experimentation: Drying of Potato Slice
- Initial mass of the potato slice (Mi) = 0.095 kg
- Final mass of the potato slice after drying (Mf) = 0.0375 kg
- Time taken for drying = 4 Hours
- Moisture Loss = 0.0575 kg
- Percentage of moisture Removed= 60.5%

![Figure 4.1. Potato slice before Drying](image1)

![Figure 4.2. Potato Slice inside of the Drying Chamber](image2)

![Figure 4.3. Dried Potato Slice](image3)
5. RESULT AND DISCUSSION

This project presents the design, fabrication and performance of a passive solar dryer for food preservation. In the dryer, the heated air from a solar collector is passed through a grain bed, and at the same time, the heat storage material absorbs the solar energy. The results obtained during the test period revealed that the temperatures inside the dryer and solar collector were much higher than the ambient temperature during most hours of the day-light. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product.

5.1. Variation Of The Temperatures In The Drying Chamber With The Ambient Temperature

Fig. 5.1 shows a typical day results of the hourly variation of the temperatures in the drying cabinet compared to the ambient temperature. The dryer is hottest about mid-day when the sun is usually overhead. The temperatures inside the dryer were much higher than the ambient temperature during most hours of the daylight. The temperature rise inside drying cabinet was up to 46 °C when outside ambient temperature was 35°C. This indicates prospect for better performance than open-air sun drying.

![Figure 5.1. Variation of Temperature in ambient and Drying chamber (preliminary Testing)](image)

5.2. Variation of The Temperatures In The Drying Chamber with The Ambient Temperature (Full Day Testing)

Fig. 5.2 shows a Full day results of the hourly variation of the temperatures in the drying cabinet compared to the ambient temperature. The dryer is hottest at the time 4 PM. The temperatures inside the dryer were much higher than the ambient temperature during most hours of the daylight. The temperature rise inside drying cabinet was up to 50°C when the ambient Temperature is 35°C. This result indicates that the Dryer can able to dry all food items with efficient time.

![Figure 5.2. Variation of Temperature in ambient and Drying chamber (Full day Testing)](image)
5.3. Performance of Heat Storing Materials When Lower Ambient Temperature

In this Research Gravel stone is used as a heat storage material. Gravel stones filled below the collector plate. While collector plate absorbs the solar energy the gravel also absorbed the heat energy. Due to gravel the heat absorbing capacity collector also increased . Fig 5.3 shows the performance of the dryer during 4pm to 7 pm. At 4pm drying chamber reaches the maximum Temperature 50°c at ambient temperature 36°c. At 5 pm ambient temperature reduced to 35°c but inside the drying chamber 50°cTemperature is maintained. This Temperature is maintained up to 2 hours. This Result shows that the gravel is working as good heat storage materials and this dryer design will be good in cloudy weather conditions.

![Figure 5.3: Variation of Temperature when ambient Temperature Reducing](image)

6. CONCLUSION

The dryer has been tested thoroughly, from the test result the following conclusions were made. The solar dryer can raise the ambient air temperature to a considerable high value for increasing the drying rate of agricultural crops. The product inside the dryer requires less attentions, like attack of the product by rain or pest (both human and animals), compared with those in the open sun drying. Although the dryer was used to dry all types of vegetables and fruits. There is ease in monitoring when compared to the natural sun drying technique. The capital cost involved in the construction of a solar dryer is much lower to that of other types of dryers. Also from the test carried out, the simple and in expensive passive solar dryer was designed and constructed using locally sourced materials. The hourly variation of the temperatures inside the cabinet is much higher than the ambient temperature during the most hours of the day-light. The dryer exhibited sufficient ability to dry food items reasonably rapidly to a safe moisture level and simultaneously it ensures a superior quality of the dried product. The main beneficiaries of this research are small scale agricultural society. Due to this research output, they can purchase solar dryer for very less price. They can avoid wasting of their product by using dryers. This new design is capable of storing solar energy so that peoples can use the dryer in evening and cloudy weather condition also.

REFERENCES