Design of an Indirect Solar Dryer, Analysis of Tray and Application in Food Processing Industries and Rural Areas

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Abstract— Energy is one of the main concerns for the growing future of any nation. It is by far the largest commodities in the world and an immense amount of energy is extracted, distributed, converted and consumed in our global society daily. The process of drying through sun in food processing industries or rural life is an integral part of various products especially vegetable, fruits and spices. There are several methods that can be used such as mechanical drying by using fossils fuel, which is costly and not environmentally friendly or open sun drying, which is very much common between farmers as compared to any other. This research paper contains the design of solar dryer according to the location of Pauri, Garhwal India and analysis of tray. The solar air heater is inclined at the angle, taking latitude in consideration, for proper trapping of energy. This paper also contains the state of various kinds of solar dryer that are widely used today and applications in various fields.

Key words: Energy, Drying, Mechanical Drying, And Open Sun Drying, Fossils Fuel, Solar Dryer

I. INTRODUCTION

Drying of leaves or foodstuffs is a very momentous post-harvest activity in a farmer's life or in herbal practitioner's life. The purpose of drying is basically to prevent the spoilage of the foodstuffs and to preserve them for a long time [1] and other reasons that could be associated with drying are to prevent the germination of seeds and make leaves gage maximum or essential ingredients. Some examples of foodstuffs that stipulate drying are tubers, vegetables, fruits, leaves and spices. Preservation of food, fruits and vegetable for long time with good quality can be achieved by drying. In this process of moisture removal due to coexisting heat and mass transfer, the safe drying process needs temperature range of 40- C of hot air. With the obligated condition at specified humidity as well as temperature, it gives superior quality of dry product rapidly [1, 2]. It is the enfeeble method of food preservation. Agricultural products mostly contain higher moisture which is gratified to25-80%, an average around 70%. Moisture appeased is the main reason for the accelerated growth of bacteria and fungi in the crops. After total removal of moisture through dehydrating, food can also regain its original condition after re-watering whenever necessary to use. Moisture content of crops when reduced to an untroubled level, it slows down the bacterial, enzyme and yeast growth. [3] Two major categories of the dryers are natural convection solar dryers and forced convection solar dryers. In the natural convection solar dryers the airflow is established by buoyancy induced airflow, while in forced convection solar dryers the airflow is provided by using external operated fan either by electricity/solar module or fossil fuel [4-7].

Uncontrolled sun drying in open air is still the most common method used to presume and process agricultural product. But the drying which is not controlled, suffers from solemn problem of wind born dust infection by insect. Products may be seriously depraved to the extent that sometime it causes less market value and it may have antagonistic economic effects on domestic and international market. Mechanical drying using fossil fuel is expansive and not environmentally friendly [8]. Most generous advantage of solar dryer is that it reduces emission of carbon particles in atmosphere [1, 2, 7, 9].These devices dry the product with proper application. There are sundry types of solar dryer [9-11].

Babagana Guttiet. al. (2012) showed how the solar dryer technology is effective for agricultural products preservation and also conferred the various evaluation methods for solar dryers [1]. V. Belessiotis and E. Delyannis(2010) presented comprehensive study of different solar drying technologies with fundamental principles and parameters [2]. A. A. El-Sebaiiet. al. has given a comprehensive review of Solar drying of products with basic details and previous work performed on solar dryer [3]. Atul H Patel et. al. (2013) again viewed the different types of solar dryer with development and performance [4]. O.V. Ekechukwua and B. Norton (1997) discussed the review of solar drying technologies for application of each design type for rural farmers in developing countries [7]. S. Vijaya Venkata Ramanet. al.(2012) presented comprehensive review of various solar drying technologies with design, development and performance evaluation also discussed the drying in off sunshine hours by using different materials [8]. B. K. Bala and Nipa Debnath(2012)presented broad review of solar dryer developments and potentials for drying of fruits, vegetables, spices, medicinal plants, and fish [9]. D. R. Pangavhave and R. L. Sawhney(2002) presented the article of different solar drying technologies with detailed development and performance for grape drying [11].

II. METHODS 0F DRYING

Microorganism causes spoilage of these foodstuffs and water is very essential to the growth of these organisms. Hence, there is a need to remove the water. Different degrees of drying can affect the quality such as color, chemical composition, potency and value of food materials. Direct solar drying, indirect solar drying and mixed mode solar drying are the three central modes to dry agricultural products.

A. Direct Solar Drying

In direct type of solar drying moisture is removed from top as air enters into cabinet from below and leaves from top. This resembles to open to the sun drying type of dryer only difference is food product is covered with the glass cover. When sun light falls on the surface of glass then three things takes place; first some light is absorbed, second some light is reflected back from the glass and third some light is transmitted through, along with the procedure a part of radiation absorbed by surface of crop which causes increase in temperature.

The glass cover reduces direct convective losses to the ambient and it plays an important role in increasing temperature of agricultural product and cabinet temperature. However, in this type of process, avoiding infestations is impossible. In many countries, very small numbers of farmers are able to produce 80% of crops during production time [15]. Mühlbauer et al. [16] studied box and tent dryers and described their performance in his work.

Drying time is large due to natural convection of air flow with low heat and moisture transfer coefficient, hence efficiency is low and this counts in disadvantage.

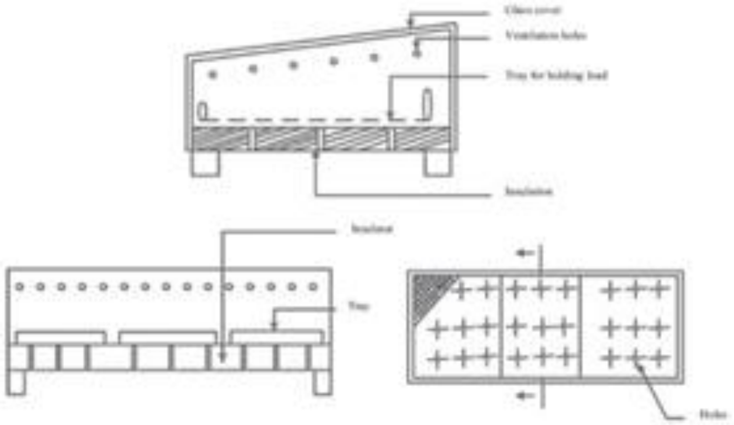

Fig. 1: Direct Solar Dryer

B. Indirect Solar Dryer

The major two categories of indirect solar dryers are natural convection solar dryers and forced convection solar dryers. In the natural convection solar dryers the airflow is established by buoyancy induced airflow while in forced convection solar dryers the airflow is provided by using fan operated either by electricity/solar module or fossil fuel. In an indirect solar dryer, the sun's heat is first collected by the solar collectors and is then passed on to the dryer cabinet, where the drying takes place. Goyaland Tiwari [18] design is shown in Fig. 2. The air that enters the chamber is heated and is then made to pass through over the wet crops. The air heaters are connected. 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 [19]. The heated air then turns in to 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.

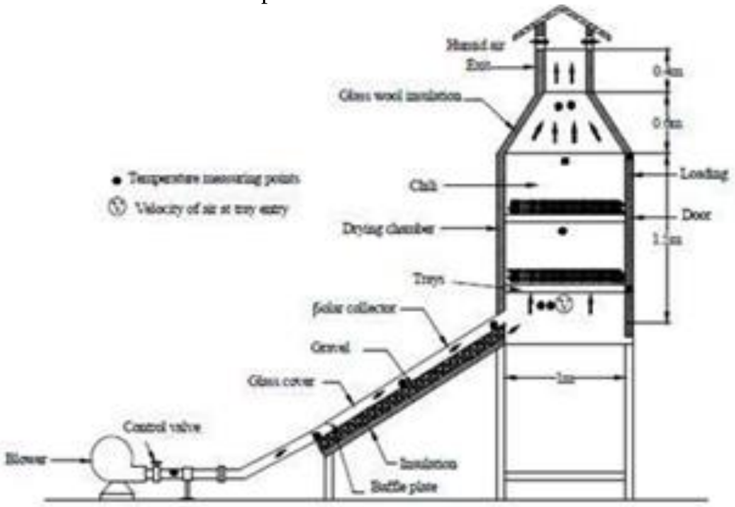

Fig. 2: Indirect Solar Dryer

C. Mixed Mode Solar Dryer

Mix mode solar dryer is the combination of direct and indirect type of solar dryer. Agricultural product is dried by directly exposure to the sun light and also by hot air supplier. Air gets heated in a collector and then this hot air is supplied to the drying chamber. Drying chamber top is also made up of glass cover. This can directly absorb solar radiation. In this way drying rate is higher as compared to direct solar drying. The governing equations were derived with respect of the drying air temperature, humidity ratio, product temperature and its moisture content [20].Olalusi and Bolaji constructed a mixed-mode solar dryer for food preservation. It was found that inside drying chamber temperature was up to 74% after 12 pm for about 3 hours. Drying rate obtained is 0.62kg/h and system efficiency obtained is 57.5% [22]. Tripathy and Kumar provide information of dryer in which flat plate collector placed in series. This dryer for drying potato slices of diameter 0.05m and thickness 0.01m [23]. Various research work related to drying process for agricultural products like mango slices [23, 24], Banana [25, 26], strawberry [25], grapes [27, 28] have been described in detail.

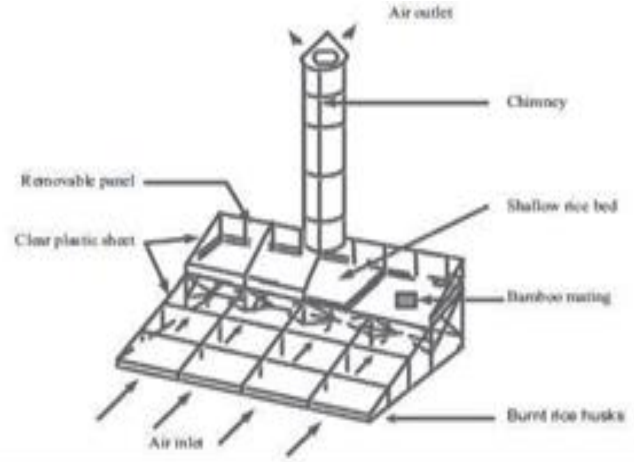

Fig. 3: Mixed mode solar dryer

III. CONCEPTUAL DESIGN

Conceptual design is one of the most important activities in product development. Inappropriate design concepts could result in high redesigns cost and delay in product awareness [30, 31]. It involves combining design features to generate as many probable design concepts. Realistic view based on the conceptual designs generated for the indirect solar crop dryer is shown in Fig 4.Different directional view, isometric view, bottom view, left view and rear view of its design are shown in Fig, 5, 6, 7. It has two parts; solar air heater and drying chamber.

Fig. 4: Realistic view of design in CATIA

A. Solar Air Heater

The solar air heater heats amass and makes the air hot, which can take the moisture from the food material or drying product kept inside the tray in drying chamber. It has dimensions of 106.68cm x 55.4cm x 15.24cm and has been constructed from 12mm thickness of ply from three sides. The top of the solar air heater was covered with glass sheet of 6mm thickness. Inside the solar heater there are 6 chambers with a gaping of10cm, to contain solar trapper such as coal in small pieces inside for increasing the heat capacity. The solar air trapper is painted in black color and the coal itself is good absorbent of heat. Coal is again broken in small pieces so as to increase the surface area to increase the efficiency by increasing drying time by 5 to 6 hrs per day as it stores heat.

Length-to-depth ratio L_C/d_C of solar collector generally lies between 5 and 10 [30]. For design we had taken (1)

Hence, the design here takes the dimension of solar collector as:

Length of the collector = 106.68cm Depth of the collector= 15.24cm

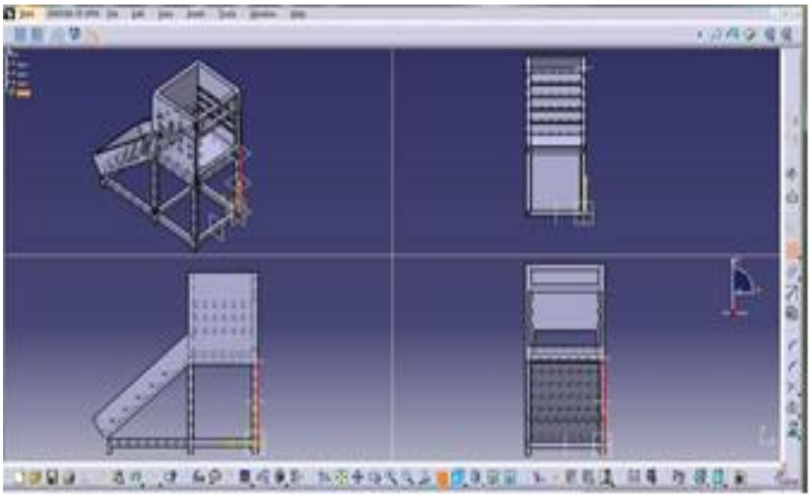

Fig. 5: Different Directional View

B. Drying Chamber

Drying chamber contains the product which has to be dried within the trays for the felicitous drying and convenience to handle the stuff. It has the cross section 61cm x 61cm and contains one inlet port and one outlet port with a door along which 3 trays (dimensions are 36.5cm x 21.25cm) can be taken in or out. This is also colored with black paint and constructed from plywood. This chamber can also be used for the storage purpose during cloudy days.

Height of the drying chamber can be determined by using the equation given bellow. The resistance to the flow of air through a parked bed of agricultural produce is expressed in the form:

(----) (2)

Where;

u= superficial air velocity which lies between 0.2 and 0.4m/s' a=constant = 0.465 /kg, for force circulation of air through agricultural produce ( )

(pressure drop across the food in the rack): = _________ (3)

Since, the total pressure across the system is twice the pressure drop across the drying rack:

= 2 = 0.176 (4)

Applying Bernoulli's equation between the relevant sections of the dryer and sampling the results leads to height of the drying chamber

-- --- -- _________________ (5)

Where;

= 298 = + = 310, = 101325,

R = 287, = 9.81 /

C. Orientation of Solar Air Heater

The flat-plate solar collector is always tilted and familiarized in such a way that it inherits maximum solar radiation according to the location, where it is kept in. The best stationary geographical orientation in Pauri, Garhwal is 29.800 N. Therefore, solar collector in this work is tilted at 39. 800 as per the calculation from angle of tilt formulae: (6)

Where, lat =latitude of collector's location

Fig. 6: Isometric view and bottom view

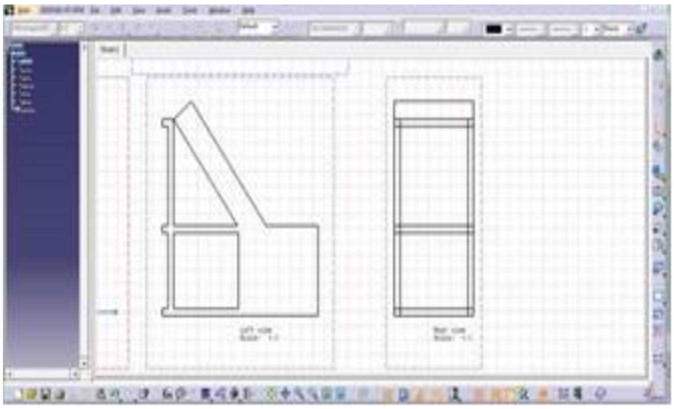

Fig. 7: Left View and Rear View

D. Drying Tray

The drying trays buttress the food material on it and are contained inside the drying chamber. Its dimensions are 36.5cm x 21.25cm. These were constructed from a layer of fine wire mesh with a fairly open structure to allow drying air to pass through the agricultural products. Its surrounding is given support on its edges by wood of 2cm wide. Slots have been made inside the drying chamber to provide support and sufficient gapping has been left from all four sides for circulation of air. Realistic view of drying tray is shown in Fig. 8. Different directional view and right and front view of tray designs are shown in Figs. 9 and 10.

Fig. 8: Realistic view of Drying tray

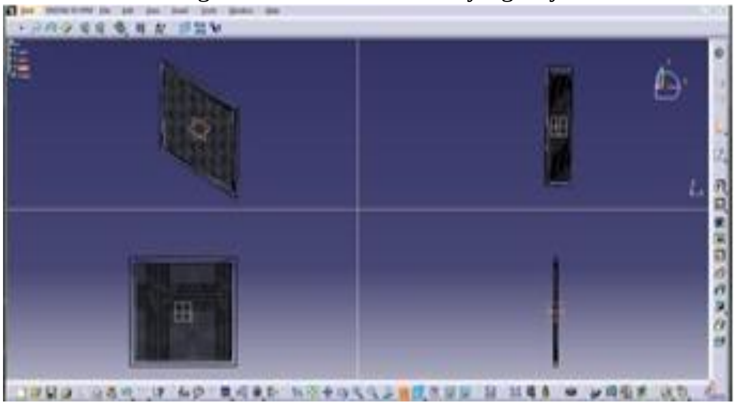

Fig. 9: Different directional view of tray

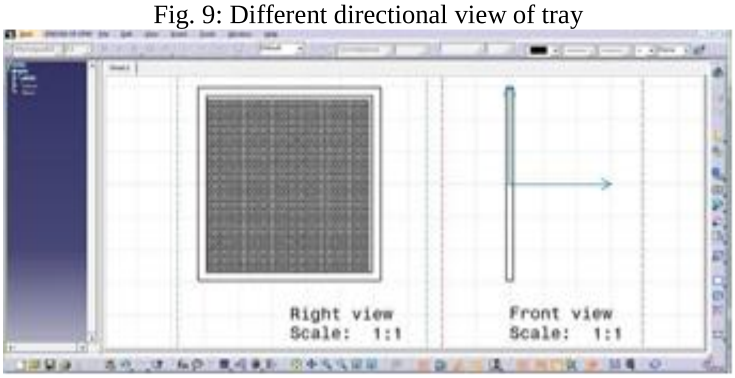

Fig. 10: Right and front view of tray

IV. ANALYSIS OF TRAY

Analysis of solar dryer trays was done on the software ANSYS. Abc analysis is done to get the various properties of the metal and the load which is to be put on the trays (Fig.10).

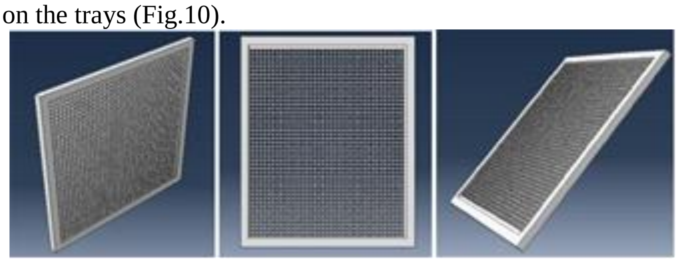

Fig. 10: Abc analysis of tray

A. Properties

1) Wood Density:

Wood density is determined by multiple growth and physiological factors compounded into ―one fairly easily measured wood characteristic‖, diameter, height, radial growth, geographical location, site and growing conditions, silvicultural treatment and seed source they all to some degree influence wood density. Variation is to be expected.

2) Steel Net:

Steel net is a steel-coated, knitted structured fabric with a net-like surface. This elegant article has a technical look. Its light transmission index is 21 – 49%; its light reflection index 18 – 46%. The white color 90 has no steel coated back and therefore possesses no light reflection values.

B. Change in Color:

When the load is applied on the tray of desired quantity, there is change in color of image as shown:

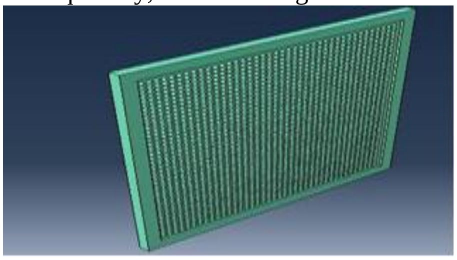

Fig. 11: Load applied

C. Boundary Conditions:

The Trays are fixed from two sides. Along with it load is applied uniformly at 4 kg. The duration for load applied is for 1 second.

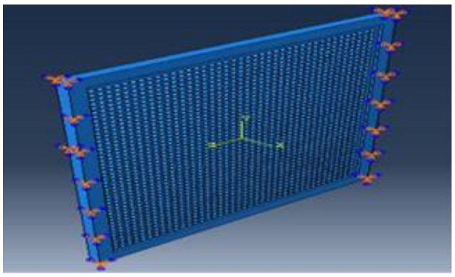

Fig. 12: Boundary conditions keeping both the sides fixed

D. Meshing:

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller sub-domains (made up of geometric primitives like hexahedra and tetrahedral in 3D and quadrilaterals and triangles in 2D). The governing equations are then discredited and solved inside each of these sub-domains. Typically, one of three methods is used to solve the approximate version of the system of equations: finite volumes, finite elements, or finite differences. Care must be taken to ensure proper continuity of solution across the common interfaces between two sub-domains, so that the approximate solutions inside various portions can be put together to give a complete picture of fluid flow in the entire domain. The sub-domains are often called elements or cells, and the collection of all elements or cells is called a mesh or grid. The origin of the term mesh (or grid) goes back to early days of CFD when most analyses were 2D in nature. For 2D analyses, a domain split into elements resembles a wire mesh, hence the name. The process of obtaining an appropriate mesh (or grid) is termed mesh generation (or grid generation), and has long been considered a bottleneck in the analysis process due to the lack of a fully automatic mesh generation procedure. Specialized software programs have been developed for the purpose of mesh and grid generation, and access to a good software package and expertise in using this software are vital to the success of a modeling effort.

E. Results:

The deflection is shown in tray if more than 3 kg weight is applied. So we apply 3 kg weight on each tray that is why the total capacity of our solar dryer is 9 kg:

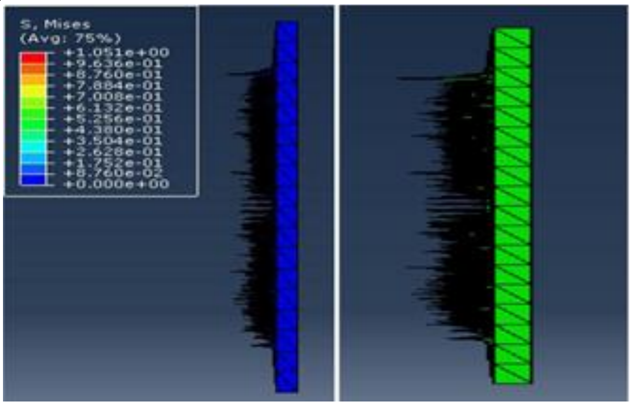

Fig. 13: Deflection angle 1

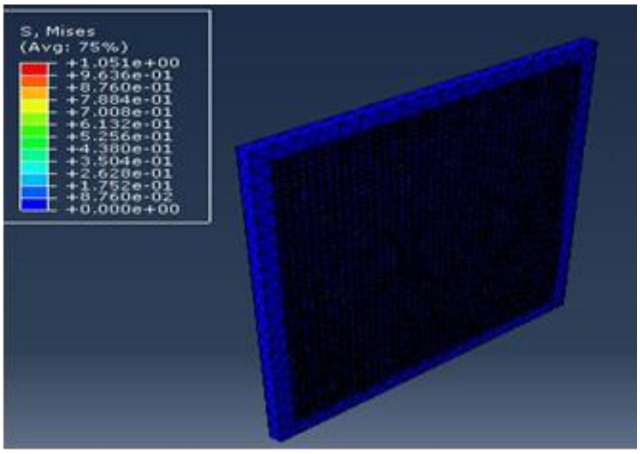

Fig. 14: Deflection angle 2

V. APPLICATION OF SOLAR DRYER

Direct solar drying is mainly used in on-firming sectors. It is also suitable for small farmers in rural areas, where electricity is not available. This kind of dryer is more efficient in drying little amounts of crops, fruits, and vegetables .A locally made indirect-type natural convection dryer is useful for drying fruits and vegetables in rural areas and can be made to use for household purpose. A solar tunnel dryer can be used for drying jackfruit bulbs and leather. The mixed-mode dryer is less in cost, readily available, and can be easily made by local farmers. Tomatoes, mango slices, and grains can be dried using this dryer, which is driven by an external force. Therefore, agricultural products are dried within a short time at ambient temperature [31]. The natural convection dryer is more advantageous and applicable than other types. The low-cost indirect- type natural convection solar dryers are used for drying cassava, bananas, and rough rice, among other products. The forced convection solar dryer is used in small firms with limited financial support from very large industrial sectors. This efficient dryer requires a short time to dry products and is built to last. The dairy industries implement solar dryer for the production of milk powder. Seasonings of wood and timber can also be achieved through it. Textile industries use it for drying of textile materials. These many ways of making use of solar energy and solar dryer more efficiently in meeting humans demand for energy and food supply [32,33].

VI. CONCLUSION

Simple and inexpensive indirect natural convection mode of solar crop dryer was designed using data of Pauri, Garhwal data. The dryer exhibited the design to be sufficient ability to dry the agricultural products at reasonably rapidly so that a safe moisture level can be attained in order to ensure superior quality of drying products. Solar dryer is an effective solution to the world's food and energy crises. With drying, most of the agricultural produce can be preserved and this can be achieved more efficiently by the use of solar dryer. The designed dryer with a tray dimension of 36.5cm x 21.25cm is expected to dry 9kg fresh food material from60% to 10% wet basis in two days under ambient conditions during harvesting period in the month of April. Locally available cheap materials can be used in construction making it available and affordable to all and sundry especially peasant farmers. This will go a long way in reducing food wastage and at the same time food shortages, since it can be used extensively for majority of the agricultural food crops. Apart from this, solar energy is required for its operation which is readily available in the tropics, and it is also a clean form of energy. It protects the environment and saves cost and time spent on open sun drying of agricultural produce since it dries food items faster. The food items are also well protected in the solar dryer than in the open sun, thus minimizing the case of pest and insect attack and also contamination.

However, the performance of existing solar food dryers can still be improved upon especially in the aspect of reducing the time of drying and probably storage of heat energy within the system. Also, meteorological data should be readily available to users of solar products to ensure maximum efficiency and effectiveness of the system. Such information will probably guide a local farmer on when to dry his agricultural produce and when not to dry them.

VII. RECOMMENDATION

A test should be under full loading conditions in order to know if all the design parameters have been met and laboratory experiment should also be done to know the effects on the nutritional values of the dried products when sun dried and solar dried.

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