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Designing, Fabrication, Performance Evaluation and Implementation of Solar-Biomass Hybrid Tunnel Dryer for Commercial Scale Drying of Several Types of Agricultural Products

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Abstract— A hybrid type solar tunnel dryer is designed and fabricated for the commercial scale drying of different fruits and vegetables. A biomass burner box along with heat exchanger is used as backup heat source, which ensure continuous drying process during night and unfavorable weather conditions. Unidirectional forced convection is developed with a volumetric flow rate of $0.11m^3/s$, by using two DC exhaust fans installed at both sides of the drying chamber. A DC blower is used to push the hot air with a volumetric flow rate of $0.02m^3/s$, generated in either biomass burner or additional solar collector. The ultraviolet rays are blocked by covering the drying chamber by UV treated transparent polyethylene sheet, it also protects the product from birds, insects, dust, wind and rain. An additional solar collector ensures the attaining of suitable drying temperature inside the drying chamber. A PV system is installed which fulfills the power requirements, makes this solar tunnel dryer new and smart. The solar tunnel dryer is installed at US - Pakistan Center for Advanced Studies in Energy located in Peshawar, latitude and longitude of 34.0151° N, 71.5249° E. The experiments are performed on this dryer, while six solar tunnel dryers are installed at Swat to harness the great potential of different fruits. The experiments for the performance evaluation of this dryer are performed during the month of June, 2019.The performance parameters attained during experimentations are: collector efficiency is 28%, drying efficiency is 22% and drying rate is 1.46kg/hr for 50 kg of load. These parameters are in the range of international standards, indicating that this solar tunnel dryer is feasible and sustainable.

Keywords— Renewable energy, solar drying, solar tunnel dryer, solar-biomass hybrid tunnel dryer.

I. Introduction

Nowadays awareness about renewable energy is growing all over the world, which plays an important role in extending the green technology in the developing countries to enhance their productivity. A significant amount of the agricultural produce in many countries of the Asia pacific region go to waste about 10 to 40%, this is due to poor infrastructure for processing and marketing [1]. Drying, refrigeration, freezing, salting (curing), sugaring, smoking, pickling, canning and bottling are several techniques adopted for food preservation. Among these drying is the most suitable technique for developing countries.

The process of removal of moisture from the product to a specified value by using heat energy is known as drying. Open sun drying is one of the oldest methods of drying agricultural products. It is a simple and cheap process. However, this method has many disadvantages such as spoilt products due to rain, wind, dust, insect infestation, animal attack and fungi. Furthermore, it requires large land area for drying [2]. Hence the sun drying is modified to solar drying to protect the agricultural products from spoilage, and improve the quality of the product.

The temperature ranges of 40 – 60oC is feasible for safe drying of most fruits and vegetables. Solar drying especially suits for developing areas where conventional fuel resources are limited or scarce. The history of solar drying is very old, backs around 18th century, to dry vegetables, fruits, fish and meat [3].

Basically there are two main types of dryers, i.e. conventional and solar, however the general concepts are the same for all type of dryers. Conventional dryers are those that use electricity or fuel to operate heaters and fans, there sub types are “high temperature” where fast drying methods are adopted, and “low temperature” where bulk storage methods are adopted. Operation of high temperature dryers need controller to monitor the temperature because high temperatures can easily over dry the products if left for even a short time. The food will harden or cook if high temperatures are used too early in the drying process. Low temperature methods are used for bulk storage often with grains and when the color and certain nutrients need to be preserved [4].

Solar drying can be categorized into three subtypes: open (natural), active and passive. Open sun drying is very common method of drying. In this method the food is exposed to open environment and sun exposure on open ground with no cover. It is estimated that 80% of the food produced in developing countries is dried by open sun drying [5]. Open sun drying method has almost no capital cost and very low running cost, for example labor work required to move the sheets in and out each day, so this method is the cheapest method of drying. Additionally, solar drying does not require any fuels for its operation, which are very expensive and led to deforestation which is a major cause of environmental degradation in Pakistan

This paper presents the designing of a suitable and feasible solar-biomass hybrid tunnel dryer for the drying of several fruits and vegetables and to fabricate a dryer from materials having great efficiency and at an affordable cost. Further, we have analyzed different factors, such as temperature inside the dryer, air flow rate, drying time, moisture content of the product and quality of the product, to evaluate the performance of the dryer. Similar solar tunnel dryer(s) have been installed in the Swat region at six villages, to harness the great potential of persimmon and other fruits of that region.

II. MATERIALS AND METHODS

A. The Dryer Design Criterion

The main aim of a dryer is to generate and supply more heat to the product, than available under the ambient conditions. This will increase the vapor pressure of the product's moisture, enhancing migration of moisture and decreasing the relative humidity of the drying air, enhancing the moisture carrying capability and ensuring a low equilibrium moisture content [6]. Further design considerations which modified this solar tunnel dryer from other developed solar tunnel dryers includes:

- Utilization of biomass as a backup heat source
- Heat exchanger with least heat loss
- Additional solar collector for achieving suitable drying temperature.
- PV system for powering exhaust fans and blowers.
- Cost competitive and using locally available materials for fabrication
- Easy to operate and efficient.

The dimensions of the drying chamber of the solar tunnel dryer are 4.8 m x 1.2 m x 1.5 m, as shown in the Fig 1. The drying chamber also works as a solar collector, as the bottom surface is painted black. The inside drying chamber is divided into six compartments. In each compartment there are three shelves where in the produce to be dried is placed. There are two vents each of 15 cm diameter for exhaust fans present on both sides of the drying chamber. At the end of one side of drying chamber the hot air enters from the additional solar collector.

The burner consists of an outer box which holds the inner box, where the biomass is placed for burning. As seen in Fig 2, the burner box has inlet pipe for blower to continue the combustion of the biomass and push the hot air to the heat exchanger through the outlet pipes. The dimensions of the biomass burner box is 47 cm x 47 cm x 70 cm.

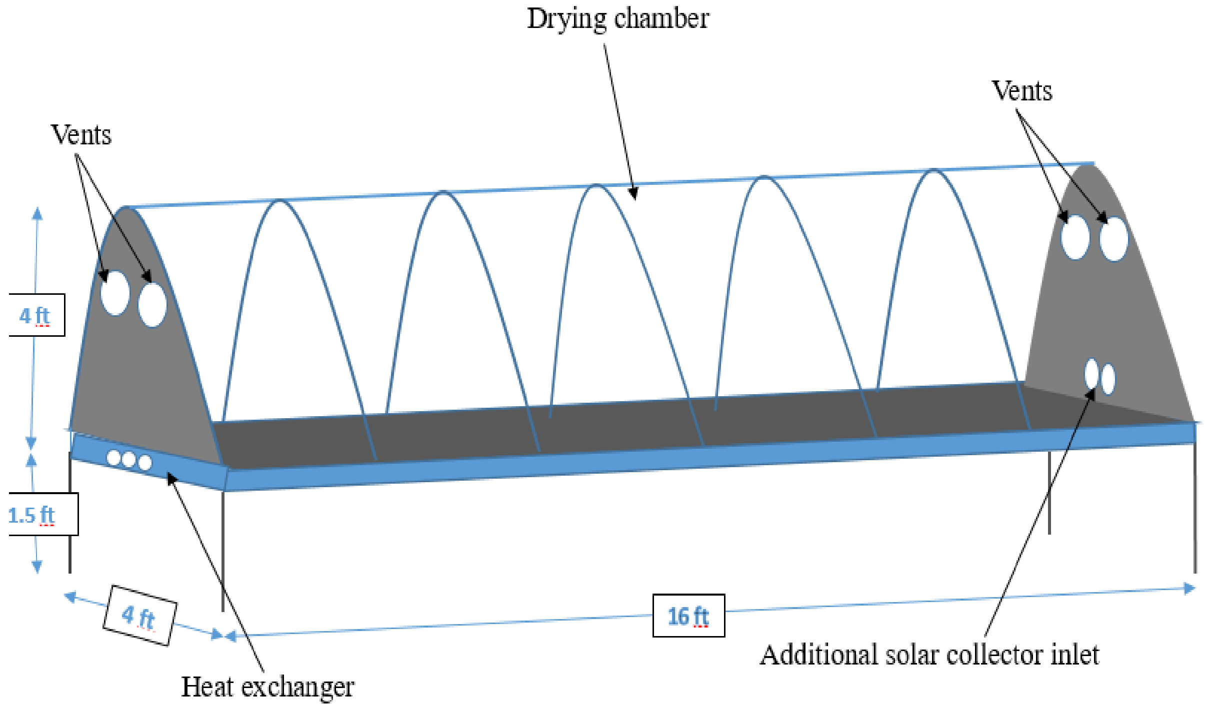

Figure 1: Schematic view of the proposed solar tunnel dryer

An additional solar collector is configured with this solar tunnel dryer to enhance the surety of attaining the suitable drying temperatures inside the drying chamber. The dimensions of this additional solar collector are 2.4 m × 2.4 m. The heat transfer is enhanced inside the solar collector by black painted wire mesh.

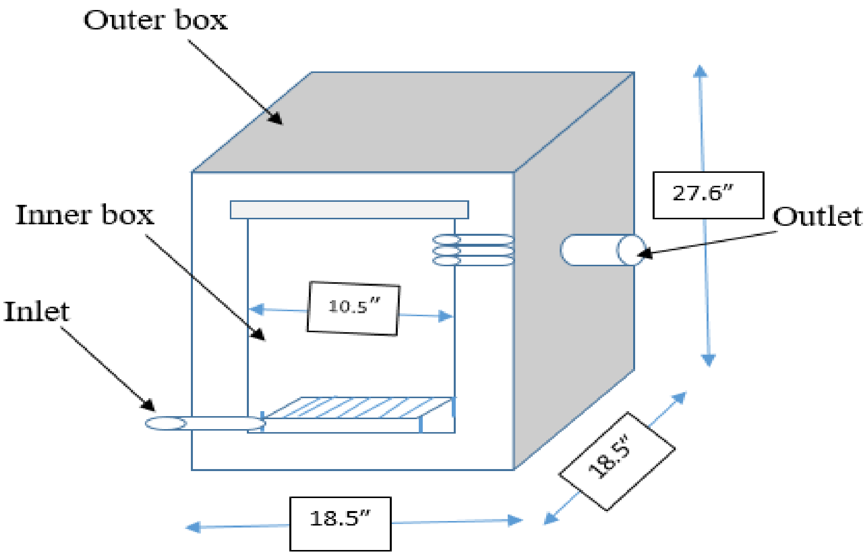

Figure 2: Schematic view of biomass burner

B. Materials used

It was preferred to use locally available materials at the cheapest price. They are selected on the basis of availability, cost, and durability amongst others. The details of items, quantity, price, contact details and reason of purchasing are listed in the table 1. These details, except the devices for experimental purposes are for one solar tunnel dryer, same as for the other six solar tunnel dryers.

C. Fabrication of the Solar Tunnel Dryer

Manufacturing the dryer with affordable cost is the main focus in this research and to make it user friendly. The solar tunnel dryer is fabricated in the workshop of Renewable Energy Engineering department of US-Pakistan Energy Center for Advanced Studies in Energy at Peshawar, Pakistan. One of the unit is installed at the same location for research purposes, while six more units have also been fabricated at the same place and later installed at six different villages of the Swat region. The whole setup of the solar tunnel dryer is portable and can easily reassembled and shifted to other places. This mode of fabrication makes it easy to shift the whole setup and installed at another location.

Table 1: Details of the materials used in each of the seven fabricated plants

S.No	Item	Quantity	Price (PKR)	Dimensions	Reason of purchasing
1	Asbestos sheet	1	3225	8×4 feet 10 mm thickness	Used as a base in the fabrication of heat exchanger to avoid heat losses to the base or surface.
4	Calcium silicate sheet	12	12×3300= 39600	600 mm× 900mm× 50mm	Used as insulation to avoid heat loss from the biomass burner box
5	Exhaust fan	4	4×1280 = 17920	6 mm dia	To enhance the forced convection inside the dryer
6	DC Blower	1	1750		To push the hot air from the biomass burner box into the heat exchanger
10	Solar charge controller	1	800 = 10400		To controlled the input and output power of solar panel and battery
11	Battery (125 amp-hr)	1	8000		To store the energy from the solar panel and then run the blower and exhaust fans
12	Solar panel (200 W)	1	6000		To generate power used by blower and exhaust fans
13	GI sheet				Top surface of the heat exchanger to transfer total heat to the drying chamber
14	Glass sheet				Cover of the additional solar collector
15	Iron mesh				To enhance air mass flow rate inside the solar collector

D. Experimental Work for Performance Evaluation

This solar tunnel dryer is designed specifically for the drying of persimmons, cultivated on a large scale in the Swat region. The season of persimmon is from October to December, so it is offseason during the month of June. This is why different types of fruits and vegetable were dried which include, mango, melon, peaches, chili, eggplant, bitter gourd, tomato and potato. The solar tunnel dryer was operated and analyzed in different modes, such as with and without additional solar collector, with only biomass and mixed mode. The temperature and relative humidity data is collected by using sensors and data loggers. The radiation incident data was acquired from the weather station installed at the US-Pakistan Energy Center for Advance Study in Energy, Peshawar, Pakistan. Anemometer was used for measuring the air mass flow rates from the blower and the exhaust fans. Moisture content was calculated by using digital weight balance.

The three most important parameters for a performance evaluation of solar collector include the collector efficiency, calculated by using equation 1. Drying efficiency calculated by equation 2, and drying rate calculated by equation 3.

$$\eta_c = \frac{\rho \times v \times C_p\,(T_C - T_{amb})}{I_s\,A_c} \qquad 1$$

$$\eta_d = \frac{W_l\,L_w}{I_T A_c} \qquad 2$$

$$\Phi = \frac{initial\ wight\ (wet) - final\ weight\ (dried)}{total\ hours\ taken} \qquad 3$$

III. Results and discussions

A. Final structure of the solar-biomass hybrid tunnel dryer

The structure of the solar dryer consists of a stand on which the heat exchanger and drying chamber are placed. The frame is fabricated from iron. The frame is fixed by long channels of iron which can be reassembled easily. The stand is fabricated in two parts for the ease of shipment. Both sides of dryer are completely closed by water proof plywood sheets containing two vents are at each side for exhaust fans as shown in the Fig 3. The total height of the structure is 1.7 m, in which the height of the stand is 0.45 m while the height of the drying chamber is 1.2 m. The length of the structure is 4.8 m and width is 1.2 m.

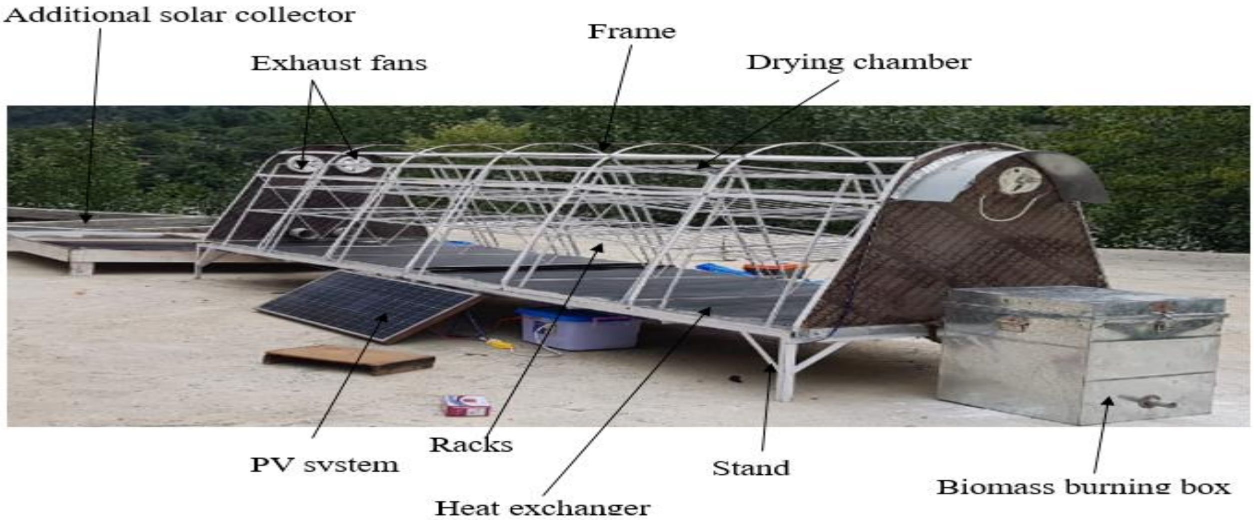

Figure 3: A view of manufactured solar tunnel dryer

The drying chamber is configured and assembled by the parabolic shaped iron frames and is fixed on the heat exchanger which are connected by iron strips, as shown in Fig 3. The surface of the drying chamber is black painted for absorption of solar radiation. Transparent polyethylene sheet of 0.6 mm width and 3.048 m × 1.34 m is used as a cover on the drying chamber, to protect the product from ultraviolet rays. Four such covers of transparent polyethylene sheet completely cover the drying chamber. The rack with three shelves is manufactured by welding of thin rods of iron. There are six racks placed in the drying chamber. Trays are made of stainless steel to ensure the quality of the product, are placed in the shelves of the racks.

B. Experimental analysis

The solar-biomass hybrid tunnel dryer was operated in two modes, solar drying and hybrid drying. The solar tunnel dryer takes total 32 hours (4 days) for complete drying, as it was operated in only solar mode. In the open sun drying tomato takes 72 hours, means 9 to 10 days to complete dry [7]. The drying time is reduced by half in the solar tunnel dryer. The quality of the tomato is preserved, taste and aroma are also preserved. The dried tomatoes are blended to powder form and is stored in small containers. The dried tomato powder is tasted and has good taste, can be used for cooking purposes. The temperatures and solar radiation relation is shown in Fig 4. The inner and outside relative humidity is show in Fig 5.

The solar tunnel dryer took a total of 66 hours for complete drying, when it was operated in hybrid mode. During day time the solar tunnel dryer was facilitated with additional solar collector. While at night time it was backup with biomass burner linked with the heat exchanger providing heat to the drying chamber. The drying process of the fruits and vegetable takes 3 complete days and nights. In the open sun drying different vegetables takes 5 to 7 days, depends on the initial moisture content present. The quality of the fruits and vegetables is preserved, taste and aroma are also preserved. The product is found to have good taste, storage in small containers prolongs their shelf life. The temperatures and solar radiation relation is shown in Fig 6. The inner and outside relative humidity is shown in Fig 7.

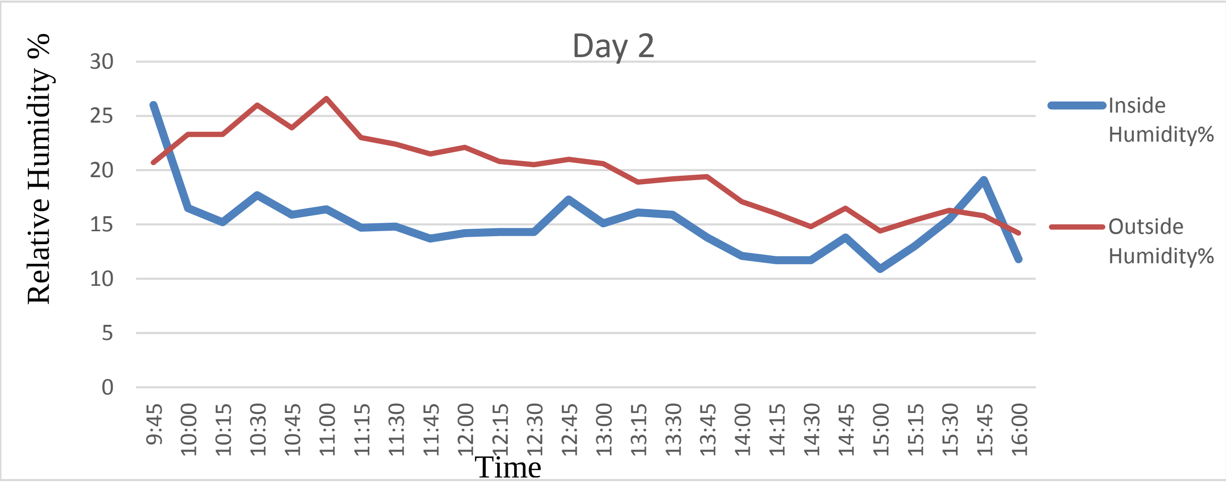

Figure 5: Relative humidity data of solar drying, Day 2, 13th June

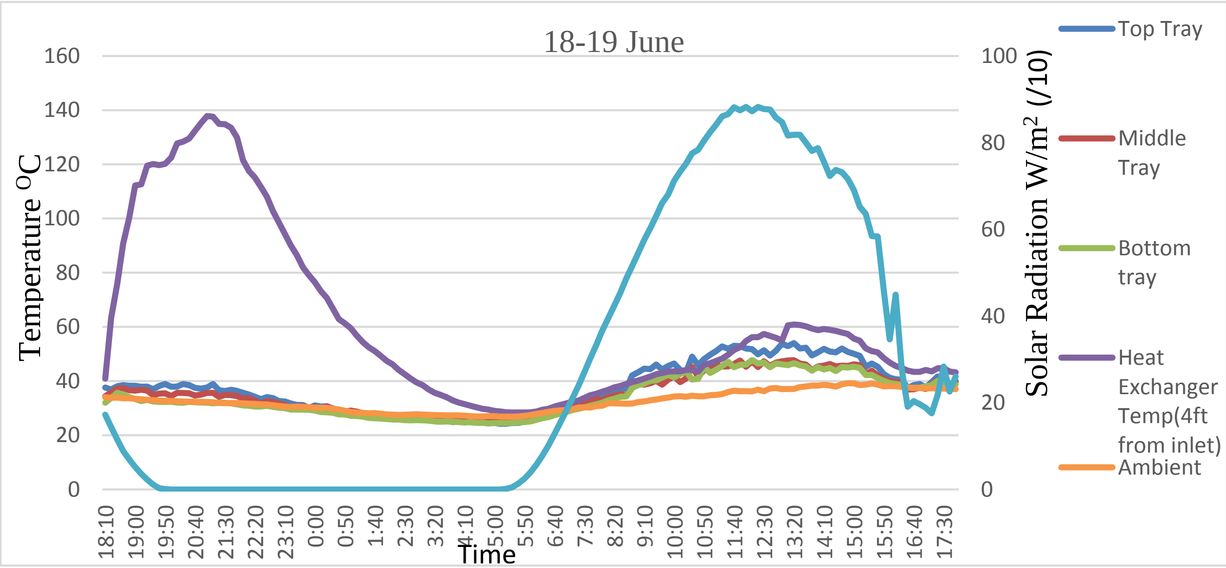

Figure 6: Relationship of drying chamber temperatures heat exchanger temperature and solar radiation for hybrid drying, Day 1 (24 hours), 18-19 June

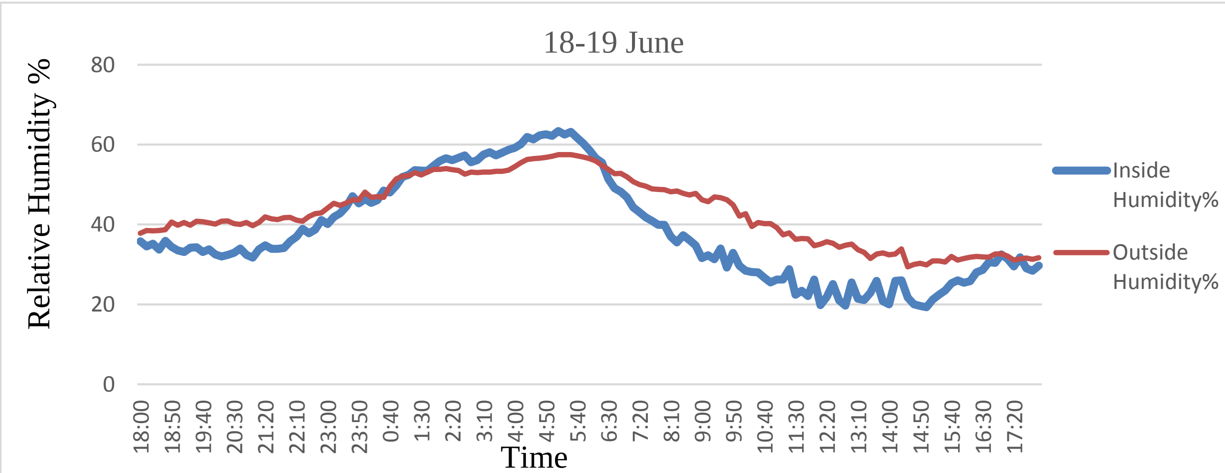

Figure 7: Relative humidity of hybrid drying, day 1 (24 hours), 18-19 June

The efficiency of drying chamber collector is calculated by using equation 1. Volumetric flow rate was calculated from exhaust fans through anemometer which was 0.11 m3/s, while the value of Cp was taken 1.006 KJ/kg °C. The efficiency is plotted against time, highest efficiency observed is 46%, while it is found that the average efficiency of the drying chamber collector is 30%. The efficiency varies due to variation in solar intensity over a day.

The drying efficiency is calculated by summing the overall radiation received by the collector during the experiment. While taking latent heat of vaporization as 2,260 kJ/kg, total weight loss as 46.9 kg and area of the collector as 64m2. Putting all these values in equation 2, the drying efficiency calculated is 22%.

The drying first increases at the start of experiment, then a constant drying phase is observed and then it tends to decrease. This is because most of the moisture which is weakly bounded, vaporizes easily and then the remaining strongly bounded moisture molecules slow down the drying rate. The maximum drying rate is observed on the second day which is 2.5kg/hour. While the overall drying rate for the solar drying is calculated to be 1.46kg/hr.

B. *Commercial scale implication*

The current designed and fabricated solar tunnel dryer is practically implemented and is installed in the Swat region. This dryer is installed at six villages of Swat, namely chikrae, tango jarae, tal sar, badalae, bondai and shingrae, to facilitate the locals to dry their produce in easy way and efficiently. The quality and quantity of the dry products is enhanced by using these solar tunnel dryers. The locals were practicing different traditional methods but now with this dryer they are drying their produce scientifically and efficiently. Fig 8 shows one of this site where this dryer is installed.

CONCLUSION

A hybrid type solar tunnel dryer is developed for the moderate scale drying of different fruits and vegetables. A biomass burner along with the heat exchanger is used as backup heat source, which ensures continuous drying process during the night and unfavorable weather conditions. Drying chamber with six compartments each having three shelves is placed above the heat exchanger. Unidirectional forced convection is developed with a volumetric flow rate of 0.11m3/s, by using a DC exhaust fans installed at both sides of the drying chamber. A DC blower is used to push the hot air with a volumetric flow rate of 0.02m3/s, generated in either biomass burner or additional solar collector. The ultraviolet rays are blocked by covering the drying chamber by UV stabilized transparent polyethylene sheet, it also protects the product from birds, insects, dust, wind and rain. An additional solar collector ensures the attaining of suitable drying temperatures inside the drying chamber. The current fabricated solar tunnel dryer can be reassembled and shifted to another place. A PV system is installed which fulfill the power requirements, makes this solar tunnel dryer new and smart.

The solar tunnel dryer installed at US Pakistan Center for Advanced Studies in Energy for experimental purpose costs approximately five lacs Pakistani Rupees. It includes the cost of tools and machines like hand drill, toolbox, electric drill, rivet gun etc. apparatus and sensors like temperature and humidity data loggers, anemometer and pyranometer. It also includes other costs such as transportation cost, labor cost and services cost.

While the other installed solar tunnel dryers, each one costs approximately two lacs and fifty thousand Pakistani Rupees. It also includes transportation cost, installation cost and labor cost. This cost can be reduced with some changes in the design and selection of materials without compromising the efficiency.

Figure 8: Badali Site

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