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Solar drying - A novel technology for arid food processing and preservation

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Introduction

Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then removing this moisture from the surface of the drying material. Drying is practised to enhance the storage life, minimize losses during storage and reduce transportation costs of agricultural products. In India, 70% of people depend on agricultural practices and these most farmers are subsistence farmers and affording hi-tech facilities and equipment is a major problem. In many rural areas of India, the farmers grow fruit and vegetables. These perishable commodities have to be sold in the market immediately after harvesting. When the production is high, the farmers have to sell the material at a very low price, thereby incurring a great loss. This loss can be minimised by dehydrating fruits and vegetables. The dried products can be stored for a longer time in less volume. On off-seasons, the farmer can sell the dried products at a higher price. The traditional method for drying agricultural produce is to dehydrate the material under direct sunshine. This method of drying is a slow process and usual problems like dust contamination, insect infestation and spoilage due to unexpected rain. These problems can be solved by using either oil-fired or gas-fired or electrically operated dryers. However, in many rural areas in India, electricity is either not available or too expensive for drying purposes. Thus in such areas, the drying systems based on electrical heating are inappropriate. Alternatively, fossil powered dryers can be used but it poses such financial barriers due to large initial and running costs that these are beyond the reach of small and marginal farmers. In the present energy crisis, it is desirable to apply a little solar technology for the dehydration of fruits and vegetables, so that gas, oil and electricity can be saved. Fortunately, India is blessed with abundant solar energy. During winter from November to February most of the Indian stations receive 4.0 to 6.3 kWhm-2 day-1 solar irradiance, while in the summer season, this value ranges from 5.0 to 7.4 kWhm-2 day-1. The arid and semi-arid parts of the country receive much more radiation as

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compared to the rest of the country with 6.0-7.4 kWhm-2 day-1 mean annual daily solar radiation having 8.9 average sunshine hours a day at Jodhpur, India, which can be used for dehydrating fruits and vegetables through the solar dryer.

Solar Energy: A Promising Source for Drying Operation

Solar energy is one of the most promising renewable energy sources in the world compared to non-renewable sources for drying agriculture and industrial products. The concept of a dryer powered by solar energy is becoming increasingly feasible because of the gradual reduction in the price of solar collectors coupled with the increasing concern about atmospheric pollution caused by conventional fossil fuels used for drying crops.

Solar drying in the context of this technical brief refers to methods of using the sun`s energy for drying but excludes air sun drying. The justification for solar driers is that they are more effective than sun drying, but have lower operating costs than mechanized driers. Several designs have been proven technically, but while none yet is in widespread use, there is still optimistic about their potential. Solar dryers are now being increasingly used since they are a better and more energy-efficient option. The solar dryer is an improved form of sun-drying in which drying is accomplished in a closed structure under relatively controlled conditions utilizing the thermal energy of the sun. Solar drying is to overcome the problems of traditional techniques and to give solutions to replace traditional techniques. If the requirement of severe drying conditions is not there, then solar drying is used for most agricultural commodities. Solar dryers are optimistic options for overcoming the problems of crop preservation with the comparison of open-air drying. Important factors to be considered in the selection for a type of solar dryer for a particular product are:

(i) The amount of product to be dried

(ii) The recommended temperature for intended use

(iii) Amount of moisture to be removed for expected storage life.

(iv) In addition to these; the intensity of solar radiation, air temperature, relative humidity and moisture content of the product are the main factors that affect the drying process.

Classification of solar dryers

Natural convection or direct type solar dryers

Non-availability of adequate irrigation water and harsh climatic condition, generally prevailing in an arid region, forces the farmer not to grow fruits and vegetables on large scale.

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As a result the community in the region largely depend on tree/bush based non-conventional and locally available fruits and vegetables, viz., "Kumtia" (*Acacia senegal*), "Sangri" (*Prosopis cineraria*), "Gunda" (*Cordiamyxa*), "Pilu" (*Salvadoraoleoides*), "ker fruits" (*Capparis decidua*) etc. These products are either consumed as fresh with little primary processing and/or after drying. The vegetable "punchkuta" is prepared using these above tree/bush based dried vegetables and is one of the well-known preparations generally served in star hotels and on certain specific occasions in the region. In the last decade or so a drastic change has occurred concerning increased consumption of conventional vegetables in the area. This has happened due to the import of these conventional vegetables from other states to the state of Rajasthan, particularly the western part. Due to this change and local market demand, the farmers of the region have started the cultivation of vegetables with their limited irrigation water resources. However, the community in the region still have a choice to consume dry fruits and vegetables. The supply of these items from neighbouring states as well as local production causes a seasonal glut in the market. Fruit and vegetables, if dried, can be stored for a longer duration after drying and it enables farmers to accrue higher benefits by selling the dried material in the off-season. Arid zones have low humidity and high irradiance and this makes the region most appropriate to use solar energy for drying fruit and vegetables. The solar dryer is a convenient device to dehydrate fruit, vegetables and industrial chemicals faster and efficiently with the elimination of problems associated with open courtyard dryings like dust contamination, insect infestation and spoilage due to rains. Among solar dryers like forced, natural, tilted and domestic types. CAZRI designed solar dryers, a low cost tilted type solar dryer, costing about Rs. 9000 per m2, has been extensively tested for drying onion, okra, carrot, garlic, tomato, chillies, ber, date, spinach, coriander, salt coated amla etc. (Fig. 1).

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Fig. 1. Inclined solar dryer installed at CAZRI solar yard

An optimally tilted type solar dryer can be used for the dehydration of fruits and vegetables. The initial moisture content of tomato was reduced from 95% (wet basis) to about 5%, in spinach 93% to 5%, in carrot 71% to 12%, in ber 80% to 20% and in lasoda/gonda it was reduced from 85% to 10% within 2 days in the solar dryer for tomato, spinach, carrot and gonda and 10 days for ber. The efficiency of the inclined solar dryer was 17.57%, respectively. The farmers can dehydrate vegetables when these are available in plenty and at a low cost. Dehydrated vegetables can be sold in the offseason when prices of vegetables are high and farmers can generate more income. The economic evaluation of the inclined solar dryer unit revealed that the high value of IRR (84.4%) and low value of the payback period (1.42 Years) make the unit is very cost-efficient. One can save about 290 to 300 kWh/m2 equivalent energy by the use of such dryers and farmers can accrue higher benefits from solar dried products. The use of the dryer would result in the reduction of the release of 1127 kg of CO_2 savings/year. Solar dried vegetables will be more acceptable in the world market and farmers will get more income.

PV winnower -cum- solar dryer for winnowing and drying of food produces:

Winnowing and drying are two important post-harvest applications, which require attention. The villagers find difficulty in cleaning the threshed material if there is a lull in natural winds, generally used for this purpose. Generally in rural areas, small farm holders thresh the material and then carry out the winnowing by pouring down the threshed material, which is kept on the locally available tray at a height with stretched hands. When the tray is shaken, the material falls down and if there is natural wind, it blows away the lighter particles and grain falls. In the absence of natural winds, the farmers are handicapped and as electrical supply is intermittent, they have to wait for the wind. The PV winnower cum dryer has been used for winnowing threshed materials in the absence of erratic and unreliable natural winds and also for dehydrating fruit and vegetables more effectively and efficiently (Fig. 2). About 35 to 50 kg grain could be separated within 1 to 1.5 hours from threshed materials of pearl millet, mustard grain and cluster bean (Fig. 3). The same fan of winnower is used in a dryer to use the system for dehydrating fruit and vegetables under the forced circulation of air. As a solar PV dryer, 40-50 kg fruit and vegetables *viz.* watermelon flakes, kachara (local cucumber) slices, grated carrot, mint, spinach, onion, mushroom, ber, coriander leaves, chillies etc. could be dehydrated in less than half of the time required in open sun drying while retaining its colour and aroma. Thus it becomes more useful for domestic lighting and for agricultural purposes such as winnowing and cleaning of grains and dehydrating fruit and vegetables enabling the farmer to get more benefits from the same system.

Fig. 2. PV winnower cum solar dryer

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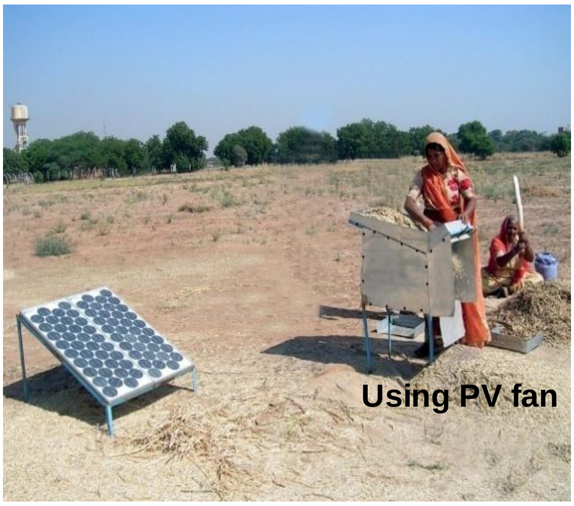

Fig. 3. Winnowing of Cluster bean (Guar)

Phase change material (PCM) based photovoltaic-thermal (PV/T) hybrid solar dryer

This solar dryer is unique as it is used both thermal and solar photovoltaic simultaneously. The same unit is being used as a solar collector as well as a solar dryer. The solar photovoltaic fan regulates the temperature uniformly when solar radiation and ambient temperature are high, then the speed of the fan is increased. The hybrid system has been designed and fabricated in such a way that it enabled the combined production of electrical energy and thermal energy from the photovoltaic panel and flat plate collector, respectively. The dryer consists of a collector unit, drying chamber, DC fan, PV panel and PCM chamber for thermal storage. The PCMs used were polyethylene glycol (PEG) 600 (melting temperature 17-23°C) during winter and polyethylene glycol (PEG) 1000 (melting temperature 33-40°C) during the summer season revealed a sufficient amount of heat storage in PCM materials during day time which further helps in drying of agricultural produces during night time. The PV module was provided on the left side of the solar collector to operate a DC fan for a forced mode of operation. Dryer had a size 1250 mm ´ 850 mm was made by galvanised steel sheet (22 gauge), which consist of four drying trays. The clear window glass (4mm thick) is provided at the top of the box. The area of collector designed for the dryer is 1.06 m2 with a DC fan of 10 watts, which was used for exhausting moisture with the help of a solar panel of 20 Wp. The dimension of two drying trays made of stainless steel angle frame and stainless steel wire mesh was (0.84 ´ 0.60 m) and that of two half trays (0.40 ´0.60 m). The drying material can be kept on four trays and placed on an angle iron frame in the dryer through an openable door provided on the rear side of the dryer. Six plastic pipes are fixed in the back wall of the dryer just below the trays to introduce fresh air at the base. The actual installation of the photovoltaic thermal (PV/T) hybrid solar dryer is shown in Fig. 4 at CAZRI solar yard.

Fig. 4. PVT hybrid solar dryer installed at CAZRI solar yard

The drying trial on dehydrating ber (*Indian jujube*), date palm, green chilli, tomato, okra, bitter gourd, spinach, carrot, anwala, nagauri methi, mint leaves, gonda, kachri (*Cucumis callosus*), ker and sangri (Khejri pods) were conducted in this dryer during the year 2019-2020. During the drying process, moisture content of Indian jujube was reduced from 82% (wet basis) to about 24%, in date palm 65% to 20%, in green chilli 89% to 6%, in tomato 94% to 5%, in okra 89% to 7%, in bitter gourd 90% to 6%, in spinach 92% to 5%, in carrot 74% to 13%, in anwala 91% to 10%, in nagauri methi 88% to 2%, in mint leaves 90% to 3%, in gonda 84% to 9%, in kachri 89% to 5%, in ker 70% to 18% and sangri 72% to 10% within 2 to 3 days in solar dryer for green chilli, tomato, okra, bitter gourd, spinach, carrot, anwala, nagaurimethi, mint leaves, gonda, kachri (*Cucumis callosus*), ker and sangri (Khejri pods) and 5-6 days for ber and date palm (Table 1). The economic evaluation of the PVT hybrid solar dryer revealed that the high value of IRR (64.60 per cent) and low value of the payback period (2.08 years) make the dryer unit very cost-efficient. The economic attributes namely benefit-cost ratio (1.90), net present worth (37988) and the annuity was (5118) of the system revealed its economic viability. The dried product of arid fruits and vegetables in the solar dryer is presented in Fig. 5.

Table 1. Drying of vegetables and fruits in PCM based PV/T hybrid solar dryer

Produce	Moisture content (wet basis) (%)		Drying temp. (°C)	Drying period (days)
	Initial	Final		
Green chilli	89.0	6.0	65.0	3.0
Tomato	94.0	5.0	62.0	2.0
Spinach	92.0	5.0	61.0	1.5
Carrot	74.0	13.0	61.0	3.0
Anwala	91.0	10.0	63.0	3.0
Gonda	84.0	10.0	64.0	3.0
Okra	89.0	7.0	63.0	3.0
Bitter gourd	90.0	6.0	62.0	2.0
Nagaurimethi	88.0	2.0	61.0	1.5
Kachri	89.0	5.0	62.0	2.5
Mint leaves	90.0	3.0	60.0	1.5
Ber	82.0	24.0	65.0	6.0
Date palm	65.0	20.0	65.0	5.0
Ker	70.0	18.0	64.0	3.0
Sangri	72.0	10.0	65.0	3.0

Fig. 5. Solar dried fruits and vegetable in PV/T hybrid solar dryer

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Summary

There are no one simple criteria for selecting an appropriate solar dryer for a specific region in the world or a specific product to be dried. The classification of solar drying systems illustrates that the solar dryer designs can be grouped systematically according to drying air circulation to natural and forced convection dryers; according to operational modes to direct, indirect, and mixed-mode dryers; and by their heating sources. The most typical solar dryers for agriculture produce based on their construction designs were summarized and evaluated. The final selection of solar drying systems is generally based on the available insolation rate, kind of product that will be dried, production throughput, operational costs, as well as the experience of the fabricator. The use of solar dryers at remote locations/rural areas can go a long way in reducing post-harvest losses as well as carbon emissions by supplementing/replacing conventional energy sources. The availability of clean and green energy sources in rural areas would enable farmers to accrue higher monetary benefits through processing and agro-based industries to improve the livelihood of farmers and enhancing their standard of living.