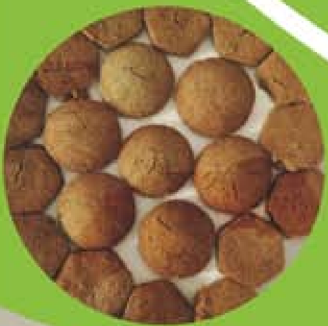
Post-Harvest Management for Economic Security of Farmers in Arid Zone



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Application of solar energy in agriculture

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Introduction

In order to keep pace with the development there is rise in energy use but it has adverse effects on greenhouse gas emissions on climate due to burning of fast depleting fossil fuels. In this context, we need to harness and use more and more renewable forms of energy, especially solar energy that is plentiful on most part of the country. Also, at several locations harnessing wind power and utilizing biomass could be effective alternatives. Solar based devices may also work in an integrated manner with small wind turbines as hybrid devices. At present, about 16% of the country's installed electricity generation capacity is contributed by renewable sources e.g. wind, solar, bioenergy, hydro etc., which is about 71.5 GW as on 31st July, 2018. In agricultural sector, energy is directly used for pumping irrigation water, operating different mechanized farm implements/tools and processing of foods. Share of agricultural sector in total energy consumption is about 7-8% and further increase in energy use from its present value of 1.6 kW ha^{-1} to 2.5 kW ha^{-1} is expected to meet the production target of next 20 years.

1. Availability of solar irradiance in India

The arid and semi-arid part of the country receives much more radiation as compared to the rest of the country. The average irradiance on horizontal surface in India is 5.6 kWh m^{-2} day^{-1} and at Jodhpur 6.11 kWh m^{-2} day^{-1}. The solar resource map of India shows that western India receives maximum amount of solar irradiation whereas major portion of India (~140 million ha) is receiving solar irradiation of 5-5.5 kWh m^{-2} day^{-1} (Fig. 1). The solar resource map along with grid wise solar radiation data can also be downloaded from http://mnre.gov.in/sec/solar-assmnt.htm. The cold arid region of the country located at Leh and Ladakh receives highest amount of radiation, which is about 7-7.5 kWh m^{-2} day^{-1}. At Jodhpur, maximum amount of radiation is received during the month of April (7.17 kWh m^{-2} day^{-1}), whereas the minimum amount of radiation is received during the month of December (5.12 kWh m^{-2} day^{-1}). In total, 6390 kWh of solar energy is available during a year at Jodhpur. Moreover, most of the days in a year at Jodhpur are cloud free which has been measured and reported in several literatures as 300 days clear sunny days in a year. Available solar irradiation and utilizable energy for any location in India can also be viewed from http://pvwatts.nrel.gov/ or http://mnre.gov.in/sec/solar-assmnt.htm.

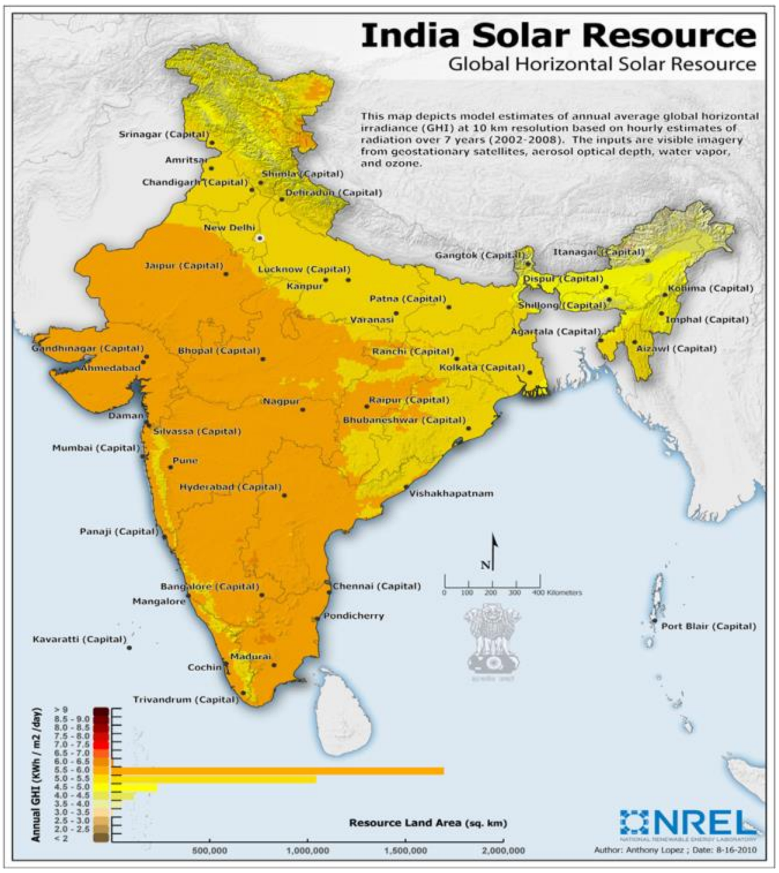


Fig.1: Solar resource map of India

2. Use of solar energy in agricultural production and processing

The utilization of solar PV and solar thermal devices is most suitable in areas which are endowed with abundant solar radiation with more than 325 clear sunny days. This eco-friendly and freely available energy can be used to supplement the energy needs for applications like solar PV pumping, PV spraying and dusting, drying, winnowing and cooking. The solar PV pump can be used for irrigation the remote farms whereas solar PV sprayer and duster are useful for plant protection. Farmers can use solar dryer for drying fruit and vegetables, which are sold by farms at throw-away prices. Winnower cum PV dryer can use for threshed the materials and cleaning of grains in the absence of erratic and unreliable natural winds and also for dehydrating fruit and vegetables more effectively and efficiently. The animal feed which is fed to milch animals by using animal feed solar cooker. These activities will enhance farm income by using solar energy in increasing crop production, reduces of post-harvest losses and increasing milk production. Overall, the scope of different solar energy sources is enormous especially in rural areas for the benefit of farmers.

3. Solar PV operated water lifting / pumping system:

Water is the primary source of life for mankind and one of the most basic necessities for crop production. The demand for water to irrigate the crops is increasing. For sustainable production from agricultural farms, irrigating the crops at right stages is highly important. Even in rainfed situation, lifesaving irrigation during long dry spell has also been found beneficial for crop survival and to obtain the targeted yield. Pressurized irrigation systems e.g. drippers, sprinklers etc. are of great importance in 'crop per drop' mission, however, ensured power supply is essential to operate these systems. Solar PV pumping systems may be quite helpful to operate the pressurized irrigation system. Specifically, solar pumps may be useful as water lifting devices in irrigation canals and also to evenly distribute water in command areas and thus will reduce the wastage of water. At present, about 16 million electric pumps and 7 million diesel pumps are in operations in the country for irrigation purpose; however, they are highly energy intensive and therefore if replaced with solar pumps may greatly contribute to country's energy security. Till December 2016, 38,687 pumps have been installed in the country, mostly of 2 or 3 HP pumping system, which has been recently appended with 5 HP pumping system. These solar pumps have the capacity to withdraw water from a depth of about 75 m and therefore may be beneficial in those areas where groundwater is not deeper than it. Moreover, solar pumps are directly operated by solar irradiance and therefore diurnal and seasonal variations of it play a key role in implementation of solar PV pumps in a place. Solar photovoltaic (PV) pumps are quite useful for irrigating the crops using solar energy. Solar PV pumps can be best used with pressurized irrigation system e.g. drippers, sprinkler etc. Small sized solar PV pumps of 1 HP capacity is best suitable to irrigate crops from surface water reservoir in to greenhouses, poly houses, shed net houses for high-value vegetable production. It has been observed in field that 1 HP capacity solar pumps with 3-4 m suction head generates a pressure of about 2-2.5 kg cm^{-2} which can operate 9 mini-sprinklers, 50 micro-sprinklers and drippers. Pressure-discharge relationship of 1 HP solar pump showed a discharge of 45-50 litres per minute when connected to 9 mini-sprinklers (Fig. 2). Solar PV pumping systems have been viewed as one of the most viable options for future energy secured agriculture. Apart from lower life cycle cost, solar PV pumping system has additional advantages over other pumping systems: (i) PV panels of a solar pumping system reduce the CO_2 emission in atmosphere at a rate of about 1360 kg CO_2 yr^{-1} m^{-2} panel area; (ii) Assured power supply in a solar PV pumping system enables the farmer to get an improvement in crop yield; (iii) During off time, electricity generated by the solar PV pumping system may be used for domestic needs and for operating small farm machines; (iv) solar PV pumping system may be used in far remote locations, where electric grids are not available. Considering the low life cycle cost and above said benefits, solar PV pumping system will obviously be considered as the first choice by farmers to irrigate crops. Ministry of New and Renewable Energy (MNRE), Govt. of India has recently launched the scheme *'Kisan Urja Surksha Utthan Mahaabhiyan* (KUSUM)' yojana in which it is planned to install 17.50 lakh standalone solar powered agriculture pumps of individual pump capacity up to 7.5 HP for replacement of existing diesel pump sets in areas where there is no source of power for irrigation across the country with a Government support of about Rs. 34,422 crores.

Fig.2. Solar PV pumping system (a) 1 HP AC pump and (b) 1 HP DC pump

4. Solar PV operated equipment for plant protection

In agriculture, a sprayer is a piece of equipment that is used to apply herbicides, pesticides, and fertilizers on agricultural crops. Sprayers range in size from man-portable units (typically backpacks with spray guns) to trailed sprayers that are connected to a tractor, to self-propelled units similar to tractors, with boom mounts of 60–151 feet in length. Approximately, 35% of the crop production is damaged if pest and diseases are not controlled at right time. Uniform spraying of liquid formulations or dusting of plant protection chemicals throughout the crop field is very important for effective control of pest and diseases. The selection of component has done according to the requirement. Following are the list of components: Tank, solar panel, DC motor, DC battery, nozzle type, connecting pipe and mounting elements. Keeping in mind these requirements, several solar PV operated equipments have been designed and developed e.g. solar PV sprayer, solar PV duster, etc. Solar PV sprayer is used for spraying of agricultural chemicals in agricultural field. To provide energy to DC pump (60 W) of the PV sprayer, 120 W_p capacity (60 $W_p \times$ 2 Nos) solar PV modules are connected so that the produced energy may be directly used by DC motor. To provide continuous supply of power to the system and other uses, a provision of battery bank (two batteries 12V, 7Ah each) is made. Performance of the solar PV sprayer showed an application rate of 84 litre h^{-1} and coverage of 0.21 ha h^{-1}. The application rate varied as per the availability of solar irradiation e.g. during 10:00 am to 11:00 am in a clear winter day at Jodhpur, the application rate was 82.2 litre h^{-1} whereas during 12:00-1:00 pm, it was 90.2 litre hr^{-1}. The capacity of the tank used in the sprayer was 30 litre and with one filling, the sprayer can cover an area of about 25 m × 25 m (Fig. 3). The approximate cost of the solar PV sprayer is Rs 25,000/-. The developed system used for spraying the fertilizer, pesticides, fungicides and painting. The solar sprayer has many advantages. Besides reducing the cost of spraying, there is a saving on fuel/petrol. Also, the transportation cost for buying petrol is saved. The solar sprayer maintenance is simple. There is less vibration as compared to the petrol sprayer. The farmer can do the spraying operation by himself without engaging labour, thus increasing spraying efficiency.

Fig.3. Solar PV sprayer

Solar PV duster is used for application of dust formulation pesticides e.g. sulphur dust, malathion powder etc. It essentially comprises a PV module (7.5 W_p), a metal carrier, storage battery (12 V, 7Ah) and especially designed compatible dusting unit. The PV module is carried over the head with the help of a light metal carrier made of aluminium sheet, which provides shade to the worker and simultaneously charges the battery to run the duster. The battery is stacked in a bracket, which is fixed in situ to the panel carrier. The field capacity of the device is about 0.075 ha h^{-1}. The unit has also the additional facility for lighting purpose during night time (Fig. 4). Approximate cost of this device is about Rs. 9000/-.

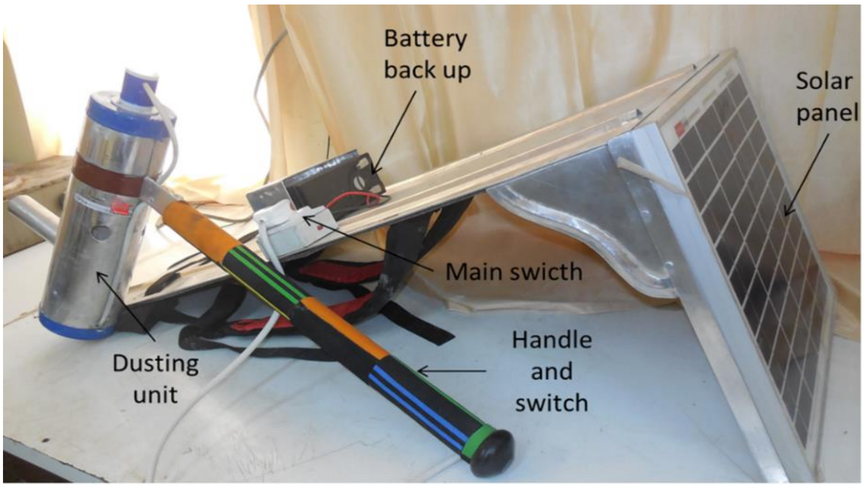


Fig.4. Solar PV duster

5. Solar Thermal Technologies

Solar energy is absorbed by a black surface and transferred to the using medium by a suitable method. Thermal insulator is provided on the bottom of the black surface to reduce conduction heat loss and covered by a transparent sheet to reduce radiation heat loss. For low temperature applications i.e. below 100°C, flat plate collector is used while for higher temperatures concentrators are used. The solar energy can be efficiently used for cooking, water heating, drying, distillation, space heating and cooling, refrigeration, and power generation in etc. in agriculture.

5.1 Solar dryer for drying agricultural produces

Drying is practised to enhance the storage life, to minimize losses during storage and to reduce transportation costs of agricultural products. In India, 70% people depend on agricultural practices and of this most farmers are subsistence farmers and affording hi-tech facilities and equipment is a major problem. Direct sun drying method has been practised since ancient time and it is still being widely used in developing countries. Although this method of drying is cheap, yet it is associated with the problems like, contamination as well as uneven drying. In order to overcome these disadvantages, the drying process can be replaced with solar drying or industrial drying methods such as hot air. Mechanical drying which is mainly used in industrialized countries as an alternative to sun drying is not applicable to small farms in India. This is due to its high investment and operating costs. 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 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 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. Solar drying has been identified as a promising alternative to sun drying for drying of fruit and vegetables in developing countries like India because of its minimal operational cost in terms of fuel cost. Utilization of solar energy for drying is advantageous because it is a free, low cost, renewable and abundant-energy source besides having environment friendly and economically viable attributes making it acceptable for use by rural farmers. It is also a more convenient alternative for rural sector and other areas with scarce or irregular electricity supply. Solar dryer is a convenient device to dehydrate fruit, vegetables and industrial chemicals faster and efficiently with elimination of problems associated with open courtyard drying like dust contamination, insect infestation and spoilage due to rains. Among solar dryers like forced, natural, tilted and domestic type. CAZRI designed solar dryers, a low cost tilted type solar dryer, costing about Rs. 9000 per m^2, has been extensively tested for drying onion, okra, carrot, garlic, tomato, chillies, ber, date, spinach, coriander, salt coated amla etc. (Fig. 5). The powdered products from some of these solar dried materials have been tested for instant use. Local entrepreneurs have adopted such inclined solar dryers of variable capacities (10–100 kg). One can save about 290 to 300kWh/m^2 equivalent energy annually 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.

Fig.5. Incline solar dryer

5.2 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 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 down. 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 have 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. 6). 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. 7). The same fan of winnower is used in a dryer to use the system for dehydrating fruit and vegetables under forced circulation of air. As a solar PV dryer 40-50 kg fruit and vegetables *viz.* water melon flakes, kachara (local cucumber) slices, grated carrot, mint, spinach, onion, mushroom, ber, coriander leaves, chilies etc. could be dehydrated in less than half of the time required in open sun drying while retaining its colour and aroma. Thus it become more useful for domestic lighting and for agricultural purposes such as winnowing and cleaning of grains and dehydrating fruit and vegetables enabling farmer to get more benefits from the same system.

Fig. 6. PV winnower cum solar dryer

Fig.7. Winnowing of Cluster bean (Guar)

5.3 Photovoltaic-thermal (PV/T) hybrid solar dryer

This solar dryer is unique as it is uses both thermal and solar photovoltaic simultaneously. The same unit is being used as solar collector as well as solar dryer. The solar photovoltaic fan regulate the temperature uniformly when solar radiation and ambient temperature are high, then the speed of 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 summer season revealed 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 at left side of solar collector to operate a DC fan for forced mode of operation. Dryer having 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 box. The area of collector designed for the dryer is 1.06 m2 with a DC fan of 10 watt, 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 angle iron frame in the dryer through an open able 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. Actual installation of the photovoltaic thermal (PV/T) hybrid solar dryer is shown in Fig. 8.

Fig.8. PVT hybrid solar dryer installed at CAZRI solar yard

Different types of arid produces were dehydrated viz. ber, lasoda/gonda, tomato, spinach, carrot, ker and sangri in this dryer. The drying drying data of ber was fitted to four mathematical models viz. Henderson and Pabis, Newton, Logarithmic and Page models to predict the behaviour of ber drying. The logarithmic model was found to be the most suitable for describing the thin layer drying behavior of ber. The effective moisture diffusivity was 3.34×10^{-7} m^2/s and the efficiency of this dryer was found 16.7%. The developed hybrid PV/T drying system produces better quality products in shorter time by the efficient use of solar energy. The economic evaluation of the hybrid photovoltaic thermal (PV/T) solar dryer revealed that high value of IRR (54.5 per cent) and low value of payback period (2.26 Years) make the dryer unit is very cost efficient. The use of this hybrid PV/T dryer will prove to be a boon for remote location/rural area with less reliable conventional energy sources. It will go a long way in reducing post-harvest losses as well as CO_2 emission.

5.4 Solar tunnel dryer

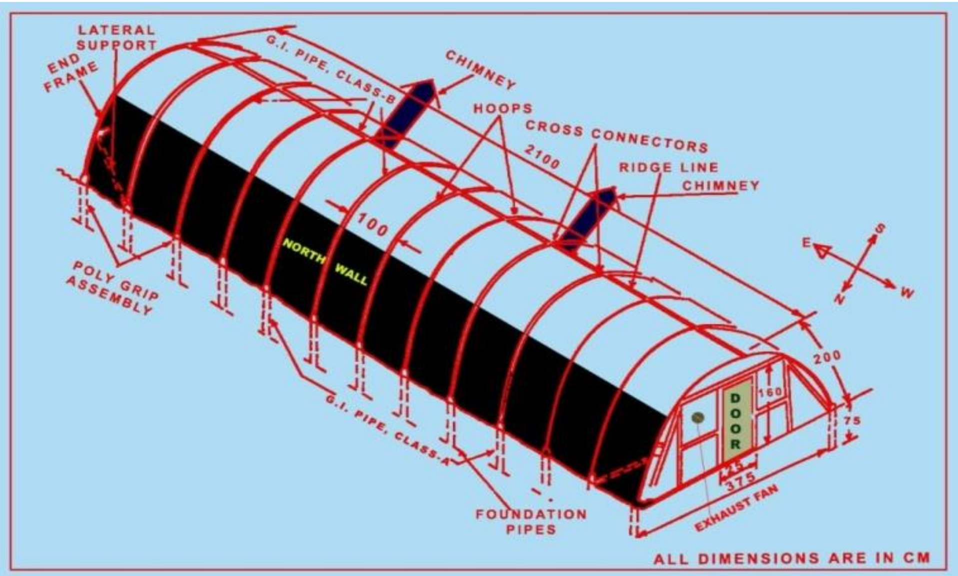
In solar tunnel dryer agriculture and industrial products can be dried on large scale and small scale. It is a poly house framed structure covered with the UV-stabilized and poly carbonate sheets. Solar tunnel dryer is cheaper in operating cost and maintains moderate environmental conditions. Loading and un-loading of the products can be done in two ways:

- One man can enter to load and un-load the dryer through door
- Two handles are provided on the upper part of the dome shaped structure for loading and un-loading of the agriculture commodities.

Main principle of the solar tunnel dryer is to pass the short-wave of solar radiation through the poly carbonate sheet and UV-stabilized polythene sheet. The transmitted solar radiations are absorbed by the inside material and the short-wave radiation turns into a long-wave radiation inside the dryer because of this reason temperature rises inside the dryer. This effect is called as a greenhouse effect and this is the basic principle used in all solar thermal collectors. Solar tunnel dryer can be useful in most of the climatic conditions.

Advantages of solar tunnel dryer

- Both the air inlet and outlet of the solar dryer are insect-tight. Insects, such as wasps or fruit flies have no access and cannot contaminate the foods or chew up parts of them.
- Less dust can collect on the goods to be dried in a dusty climate.
- A brief episode of rain does not affect the drying results adversely
- Achievement of temperature is more inside the solar tunnel dryer compare to ambient temperature
- No running operating costs, environmentally friendly, energy self-sufficient.



Schematic diagram of solar tunnel dryer

5.5 Greenhouse dryers

Greenhouse dryers could be classified either as direct solar dryers or sometimes as mixed-mode dryers. The greenhouse dryer is low cost, easy to fabricate, and simple in design. This can be used in any part of the world. Based on the mode of air circulation, the greenhouse dryers are classified into two types: (i) greenhouse dryer under passive mode (natural convection) and (ii) greenhouse dryer under active mode (forced convection). The typical design of greenhouse dryer is presented on Fig. 9. The original greenhouse configuration was modified to allow for a black galvanized iron sheet absorber at the floor, air inlets along the whole length of both sides of the dryer, and air outlets along the upper part of the dryer. Both exits are equipped with fine plastic netting to protect the product against insects and dust.

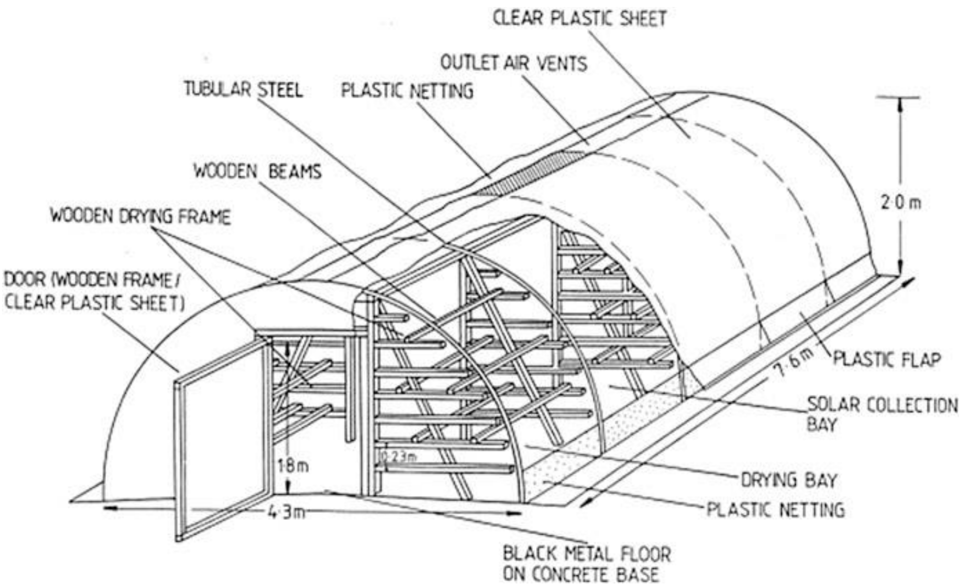


Fig. 9. Natural circulation greenhouse dryer

Another type of forced convection greenhouse dryer with transparent polycarbonate cover is visible in Fig. 10. The dryer is approximately 5m wide and 10m long, and it is suitable for drying of different commodities such as fruits, vegetables, and spices. The dryer has trays stacked inside a wooden shed. Trays of size 2m ×2m are fixed in the wooden chamber to spread grapes. The air temperature inside the greenhouse dryer is approximately about 20°C higher than the ambient temperature depending on specific climatic conditions. Heated air passes through the trays placed in the wooden chamber. A blower is placed on the backside of the stack chamber to ensure a regular airflow through the trays. The size of the dryer shed is fixed at 2×3m which ensure easy loading. The frame is made from metal, and the dryer was covered by clear polyethylene material. The dryer consists of a plastic greenhouse cover containing a drying tunnel made with transparent plastic walls. The air circulation is ensured by an electric fan that moves the hot air from the greenhouse into the tunnel.

Fig.10. Solar greenhouse dryer

The main advantages of this dryer are continuous production, lower labour cost since the product handling was partly mechanized, a conventional heater which can be easily installed to keep a constant thermal efficiency, and the installation which can be used as a greenhouse for small production when it is not used as a dryer. Same authors investigated the evaporation rate in two types of forced convection greenhouse dryers, the single- and the double-chamber system.

6. Animal feed solar cooker for milch animals:

In the arid western Rajasthan, animal husbandry contributes a major portion of the income of rural people. Livestock provides a range of benefits to rural people e.g. provides nutritious milk for domestic use, helps in income generation through sale of milk in local markets, provides manures to maintain soil fertility etc. Thus, it plays a major role in generating employment and reducing poverty in rural areas. Apart from it, livestock are commonly used for draft power in farm operations. However, these benefits can be availed if digestive and nutritive feeds are given to these livestock animals. Boiling the animal feed helps in improvement of digestive and nutritional quality of the feed which in turn improves both the milk quality and quantity. Therefore, rural people in arid western Rajasthan generally boil the animal feed daily before giving it to livestock. Firewood, cow dung cake and agricultural wastes are commonly used for boiling purpose. This traditional practice does not ensure the quality feed because it requires slow cooking. Solar cooking is the most suitable option to prepare the animal feed. Moreover, drudgery involved in conventional boiling process can also be avoided in solar cooking and it also saves fuel wood. Therefore, a low cost high capacity suitable solar cooker has been designed for boiling of animal feed using solar energy. The animal feed solar cooker was fabricated using locally available materials e.g. clay, pearl millet husk and animal dung (Fig. 11). About 10 kg of animal feed can be boiled in a single animal feed solar cooker per day. The performance of the animal feed solar cooker can be improved by providing an additional reflector during extreme cold days. Crushed barley (*JauGhat*), *guar korma*, and *gram churi*with water can be successfully boiled using the animal feed solar cooker between 9 AM and 3 PM. Animal feed viz. cotton seed and *khal* have also been successfully boiled by farmers using the animal feed solar cooker. The solar cooker saves time of farm women and 1059 kg of fuel wood is saved per year which is equivalent to 3611 MJ of energy. It is easy to fabricate at village level at a cost of about Rs. 9000 per piece with the help of a carpenter who will get job for the fabrication of glass frame which is also very simple. Conservation of firewood helps in preserving the ecosystem and animal dung cake could be used as fertiliser, which will enhance agricultural productivity. The technology developed for the animal feed preparation not only reduces the greenhouse gas emission but also helps in fuel conservation and drudgery reduction. Moreover, the use of the solar cooker for animal feed would result in the reduction of the release of 1442.64 kg of CO_2 savings/year. Meanwhile, money can also be saved, which will help to strengthen the financial status of the marginal rural farmers, if used on regular basis.

Fig.11. Solar cooker for animal feed with reflector

7. Solar PV and thermal technology for enhancing farmer's income

The solar PV pump can be used in remote farms and can replace electric and diesel pumps due to its lower life cycle cost. In addition, it can reduce about 1360 kg CO_2 emission yr^{-1} m^{-2} panel area and annual benefits of Rs. 11000/year from electricity generation by using 1 HP solar PV pumping system. Solar PV duster and sprayer can be used for plant protection from PV generated power and improvement in crop productivity. The solar dryer which costs about Rs. 9000/- m^2 can dehydrate fruit and vegetables and provide about 100 kg of dried fruit and vegetables and can fetch about Rs. 5000-6000 of annual benefits with a payback period of less than two years. It can reduce 1127 kg CO_2 emission annually. The PV winnower can be used and 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. The animal feed solar cooker can cook about 10 kg animal feed per day which is sufficient for three milch animals. It can increase milk production by 20%. The animal feed solar cooker saves about 1000 kg of fuel wood annually thereby reducing about 1442 kg of CO_2 emission annually. The solar PV and thermal devices can ensure clean environment and check deforestation to a great extent.

Summary

These solar PV and thermal devices will be very useful in increasing crop production, processed product and milk production in addition to supplementing conventional energy sources. These devices will ensure increased farmer's income by carrying out integrated activities. Last but not the least there will be reduce CO_2 emission to a great extent.

Way forward

The scope of solar thermal energy in agricultural production and processing sectors is tremendous. It can supplement conventional energy sources to a great extent to make the arid zone more self-dependent on energy. The use of renewable energy will not only curtail the consumption of fast depleting conventional fuels but also reduce greenhouse gas emissions. There is a great need of promoting the solar thermal energy by disseminating these eco-friendly technologies for the sustainable development of society. It requires active participation of users/industrialist and researchers. The availability of clean and green energy source 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.