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Use of solar energy in

agricultural production and processing

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The utilization of solar PV and solar thermal devices is 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 in the remote farms whereas solar PV sprayer and duster are useful for plant-protection. Farmers can use solar dryer for drying fruits 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 fruits 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, reduce of post-harvest losses and increase milk production.

Key words: Animal feed, PV sprayer and duster, Solar, Solar dryer, Winnower

THE development of any region is reflected in its quantum of energy consumption. With a view to keep pace with development we have to grow our energy resources @ min. 6%. The electricity problem is more severe in rural areas of India where 70% of population live and have agriculture as the main occupation. However, statistically few thousand villages are yet to be electrified, the availability of regular supply in far off places is a problem and the farmers are unable to derive benefits of electricity. The fast depleting kerosene is used for lighting and diesel oil for running agricultural machinery including pumps. Besides people burn firewood, agricultural waste and cow dung-cake for cooking food causing irreparable damage to the eco-system. In the context of rural economy, energy is basically needed for cooking food, heating of water; lighting of houses at the domestic front while in agricultural sector energy is required for field operations, pumping water, spraying of insecticides, post-harvest activities and running of agro-and cottage industries. The situation is still worse in arid region where biomass is scarce and there is no hydro-electricity. Besides, farmers are unable to generate additional income due to lack of energy resources to run appropriate device in cottage industries. The arid and semi-arid part of the country receives higher radiation than rest of the country with 6.0 $kWhm^{-2}day^{-1}$ mean annual daily solar radiation received at Jodhpur having 8.9 average sunshine hr/day. Further, it was estimated that solar energy of 1% of land area, wind power of 5% of land area and biogas (80% collection efficiency) can provide 1504 kWh $year^{-1}$ energy per caput in arid region while the average per caput total energy consumption of India is 1,122 kWh $year^{-1}$.In this context, renewable sources of energy like solar energy, wind power and biogas need to be harnessed for the sustainable development in general and catering the farmer requirements in particular.

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, life saving irrigation during long dry spell was 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

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


Fig. 2. Solar photovoltic sprayer

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, pumps (38,687) were installed in the country, mostly of 2 or 3 HP pumping system, which was recently appended with 5 HP pumping system. These solar pumps had 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 photovoltaic pumps in a place. Solar photovoltaic photovoltaic pumps are quite useful for irrigating the crops using solar energy. Solar photovoltaic pumps can be best used with pressurized irrigation system e.g. drippers, sprinkler etc. Small-sized solar photovoltaic pumps of 1 HP capacity is best suitable to irrigate crops from surface water reservoir in to greenhouses, polyhouses, shed net houses for high-value vegetable production. The study showed in field that 1 HP capacity solar pumps with 3-4 m suction head generates a pressure of about 2 to 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 to 50 litres/min. when connected to 9 mini-sprinklers (Fig. 1). Solar photovoltaic pumping systems viewed as one of the most viable options for future energy secured agriculture. Apart from lower life-cycle cost, solar photovoltaic pumping system has additional advantages over other pumping systems:

(*i*) photovoltaic panels of a solar pumping system reduce the CO_2 emission in atmosphere @ 1,360 kg CO_2 yr^{-1} m^{-2} panel area;

(*ii*) Assured power supply in a solar photovoltaic pumping system enables the farmer to get an improvement in crop yield;

(*iii*) During off time, electricity generated by the solar photovoltaic pumping system may be used for domestic needs and for operating small farm machines;

(*iv*) solar photovoltaic 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 photovoltaic pumping system will obviously be considered as the first choice by farmers to irrigate crops.

Solar photovoltaic operated equipment for plant-protection

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 important for effective control of pest and diseases. In view of these several solar photovoltaic operated equipments were designed and developed e.g. solar photovoltaic sprayer, solar photovoltaic duster, etc.

Solar photovoltaic *sprayer*: It 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 × 2 Nos) solar photovoltaic 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 photovoltaic 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. from 10:00 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^2 × 25 m^2 (Fig. 2). The approximate cost of the solar photovoltaic sprayer is ₹ 25,000.

Solar photovoltaic duster: It is used for application of dust formulation pesticides e.g. sulphur (S) dust, malathion powder etc. It essentially comprises a photovoltaic module (7.5 W_p), a metal carrier, storage battery (12 V, 7Ah) and especially designed compatible dusting unit. The photovoltaic module is carried over the head with the help of a light metal carrier made of aluminium (Al) 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 (Fig. 3).

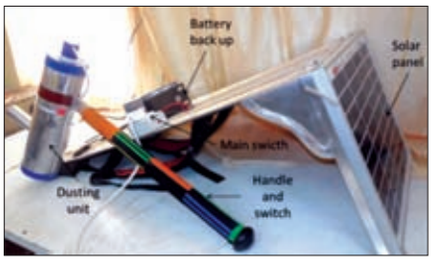

Fig. 3. Solar photovoltaic duster

Approximate cost of this device is about ₹ 9,000.

Solar dryer for drying agricultural produces

Non-availability of adequate irrigation water and harsh climatic condition, generally prevailing in arid region, forces the farmer not to grow fruits and vegetables on large-scale. 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' (*Cordia myxa*), 'Pilu' (*Salvad oraoleoides*), 'ker fruits' (*Capparis decidua*) etc. These products are either consumed as fresh with little primary processing 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 last one decade or so a drastic change occurred with respect to increased consumption of conventional vegetables in the area. This has happened due to the import of these conventional vegetables from other states to Rajasthan, particularly western part. Due to this change and local market demand the farmers of the region started 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 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 off season. Arid zones have low humidity and high


Fig.4. Solar dryer

irradiance and this makes the region most appropriate to use solar energy for drying fruits and vegetables. Solar dryer is a convenient device to dehydrate fruits, 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 ₹ 9,000/ m^2, was extensively tested for drying onion, okra, carrot, garlic, tomato, chillies, *ber*, date, spinach, coriander, salt coated amla etc. (Fig. 4). The powdered products from some of these solar dried materials were tested for instant use. Local entrepreneurs adopted such inclined solar dryers of variable capacities (10–100 kg). One can save about 290 to 300 $kwhm^{-2}$ 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 1,127 kg of CO_2 savings/yr. Solar dried vegetables will be more acceptable in the international 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 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 were used for winnowing threshed materials in the absence of erratic and unreliable natural winds and also for dehydrating fruits and vegetables more effectively and efficiently (Fig. 5). About 35 to 50 kg grain could be separated within 1 to 1.5 hr from threshed materials of pearl millet, mustard grain and cluster bean. The same fan of winnower is used in a dryer to use the system for dehydrating fruits and vegetables under forced circulation of air. As a solar PV dryer 40 to 50 kg fruits 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 fruits and vegetables enabling farmer to get more benefits from the same system.

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

Fig. 5. Photovoltic winnower-cum-solar dryer

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, cowdung 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 was 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. 6). About 10 kg of animal feed can be boiled in a single animal feed solar cooker/day. The performance of the animal feed solar cooker can be improved by providing an additional reflector during extreme cold days. Crushed barley (*Jau ghat*), *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* were successfully boiled by farmers using the animal feed solar cooker. The solar cooker saves time of farm women and 1,059 kg of fuel wood is saved per year which is equivalent to 3,611 MJ of energy. It is easy to fabricate at village level at a cost of about ₹ 9,000/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 fertilizer, 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/yr. Meanwhile, money can also be saved, which will help to strengthen the financial status of the marginal rural farmers, if used on regular basis.

Solar photovoltic and thermal technology for enhancing farmers' income

The solar photovoltic pump can be used in remote farms and can replace electric and diesel pumps due to its lower life cycle cost. Besides, it can reduce about 1,360 kg CO_2 emission yr^{-1} m^{-2} panel area and annual benefits of ₹ 11,000/year from electricity generation by using 1 HP solar photovolticpumping system. Solar photovoltic duster and sprayer can be used for plant protection from photovoltic generated power and improvement in crop productivity. The solar dryer which costs about ₹ 9,000/m^2 can dehydrate fruits and vegetables and provide about 100 kg of dried fruit and vegetables and can fetch about ₹ 5,000-6,000 of annual benefits with a payback period of less than two years. It can reduce 1,127 kg CO_2 emission annually.

The photovoltic winnower can be used and about 35 to 50 kg grain could be separated within 1 to 1.5 hr 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

Fig. 6. Solar cooker for animal feed with reflector

solar cooker saves about 1,000 kg of fuel wood annually thereby reducing about 1,442 kg of CO_2 emission annually. The solar photovoltic and thermal devices can ensure clean environment and check deforestation to a great extent.

SUMMARY

These solar photovoltic 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 farmers' income by carrying out integrated activities. Last but not the least there will be reduction of CO_2 emission to a great extent.

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.

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