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Utilization of Solar Thermal Devices for Farming Community of Hot Arid Region of Rajasthan

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The sun is a huge source of solar energy. Work on the utilization of such a huge, non-polluting and everlasting energy source has been carried out at CAZRI, Jodhpur for various domestic, industrial and agricultural applications in order to supplement the energy demand. This includes the development of a lot of solar thermal devices, such as, solar dryer, non-tracking, animal feed solar cooker; solar PV dryer cum winnower, PCM based hybrid PVT solar dryer and solar candle device, etc. The details of some of these devices are given in this article.

Introduction

The sun is an abundant source of solar energy (average value on horizontal surface 6 kWm^{-2} per day), which is freely available. This huge source of energy is non-polluting and inexhaustible in nature. It has the potential of supplementing the conventional energy sources to a great extent. There is acute shortage of conventional energy sources, which affects the overall development. Work on the utilization of such a huge, non-polluting and everlasting energy source has been carried out at CAZRI, Jodhpur for various domestic, industrial and agricultural applications in order to supplement the energy demand. This includes the development of a lot of solar thermal devices, such as, solar dryer, non-tracking, animal feed solar cooker, solar PV dryer cum winnower, PCM based hybrid PVT solar dryer and solar candle device etc. The details of some of these devices are given as following:

1. Solar Cooker for Animal Feed

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, livestocks 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 livestocks. 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. 1). 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 (*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* 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. 1: Animal Feed Solar Cooker

2. Non Tracking Solar Cooker

With fast growing population and rapid growth of industries, consumption of energy is increasing enormously. If the rate of energy consumption continues to be the same as its present rate, total energy resources of the world will be exhausted in next 50 to 100 years. Therefore, there is need to harness alternate energy sources e.g. solar energy, wind energy, biofuels etc for future energy security. Solar cooking has been proved to be one of the simplest, viable and attractive options for solar energy utilization and also found environmental friendly and cost effective. Even the solar cooker is very useful for common people in developing world specifically because of its low drudgery. A major portion of total available energy resource in rural areas of developing world is utilized for cooking and is mainly supplied by non-renewable

energy sources e.g. fuel wood, agricultural waste, cow dung, kerosene etc. For example, 50% of total energy consumption in India is used for cooking purpose. Therefore, there is huge potential to replace these non-renewable sources of energy for cooking purpose by solar based cooking devices. To eliminate tracking completely and meet requirement of about 10 people, a non-tracking solar cooker (Fig. 2) has been designed and fabricated. This cooker can be used for boiling rice, lentil, vegetables, roasting groundnut, potato, cooking local food and feed for animals. Length to width ratio of the cooker has been designed as 3:1 so that maximum amount of radiation falls on the glass window any time during the day. It helped in eliminating the need for azimuthal tracking of the cooker, which is very essential for a simple hot box solar cooker. By using the non-tracking solar cooker one can save about 30-40% of fuel requirement. The efficiency of the non-tracking solar cooker has been found to be 29.5 %. The thermal performance of the developed non-tracking solar cooker was tested as per different test procedures as standardized by American Society of Agricultural Engineers (ASAE) and Bureau of Indian Standards (BIS). The first figure of merit, second figure of merit and the standard cooking power (P50) were found 0.120, 0.401 and 46.40 W, respectively, which indicate that the developed cooker falls under category "A", as per standard. The cooker saves 2587.5 MJ of energy per year. The cost of the cooker is Rs. 9000.00 (1.0 US$ = Rs.67.16). The payback period of the solar cooker was calculated very low (1.58 yr) as compared to firewood, electricity, charcoal, LPG and kerosene based cooking.

Fig. 2: Non Tracking Solar Cooker

3. Solar Candle Machine

The conventional methods of preparing candles from wax are unhygienic, need attendance during wax melting process and also suffer from many other drawbacks. The solar method is quite safe, convenient and obviates any type of care or attendance during intermediate melting process of raw materials. Operation and maintenance of the solar candle device (Fig. 3) is easy. The working of the device for production of candle is simple. It needs no extra space and can be operated in the house itself or in the field. One time attention is sufficient for daily production of candles/wax lamps by solar candle device. The paraffin wax is loaded once a day in the solar machine and then machine is left intact. The melting process takes place in the solar machine during the day and melted material is collected from it for candles or wax lamps production in the evening. The time period of 2 to 3 hours in the evening is sufficient for the candle

production. The candle production from a small unit of solar machine is 10-16 kg day^{-1} during summer season and 6-9 kg day^{-1} during winter season. The dimensions of the wax melter are as given below:
Absorbing area - 0.5 m^2
Loading capacity - 18kg wax
Total dimensions - 106× 75× 20 cm
The cost of the wax melter including mould was comes to about Rs. 12000/-

Fig. 3: Solar Wax Melting Device

4. Solar Dryer

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" (*Salvadora oleoides*), "ker fruits" (*Capparis decidua*), etc. These products are either consumed as fresh with little primary processing and/or after drying. In last one decade or so a drastic change has 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 the state of Rajasthan, particularly western part. Due to this change and local market demand the farmers of the region have started cultivation of vegetables with their limited irrigation water resources. However, the communities 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 irradiance and this makes the region most appropriate to use solar energy for drying fruit and vegetables. Solar dryer (Fig. 4) 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. 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). The efficiency of the dryer was found to be 17.57 %. The economic evaluation of the solar dryer revealed that high value of IRR (84.4 per cent) and low value of payback period (1.42 years) make the dryer unit very cost efficient. One can save about 290 to 300kWh/m^2 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 on the reduction of the release of 1127 kg of CO2 savings/year. Solar dried vegetables will be more acceptable in the world market and farmers will get more income. The dryers are finding increasingly more acceptability due to export potential of dried products like garlic, onion, instant chatni etc. Based on this design a solar dryer of 400 kg capacity has been installed in village Kankani and of 1000 kg capacity at village Keru village of Jodhpur district.

Fig. 4: Inclined Solar Dryer

5. PV Winnower-Cum- Solar Dryer

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 (Fig. 5) 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. 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 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 (Fig. 6) of grains and dehydrating fruit and vegetables enabling farmer to get more benefits from the same system.

Fig. 5: PV Winnower-cum- solar Dryer

Fig. 6: Thrashing by PV Winnower

6. Phase Change Material Based PVT Hybrid Solar Dryer

A phase change material (PCM) based photovoltaic thermal (PV/T) hybrid solar dryer (basal area 1.06 m^2) which has combined production of electric energy and thermal energy from the photovoltaic panel and flat plate collector. The dryer (Fig. 7) 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. 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.

Fig. 7: PCM based PVT hybrid solar dryer

7. Solar Desalination Device

Solar desalination device (Fig. 8) is very much useful in rural arid areas which are deprived of potable water and only saline water is available. The device is very cost effective can provide 8 to 10 litres of distilled water per day on clear sunny days. The solar still can be successfully used for desalination of saline water in rural areas for meeting requirement of potable water. The distillate output of solar still can be mixed with the available saline water in appropriate proportion to make it drinkable. In fact as much as 20 litres/day of potable water (150 ppm TDS) can be made available in a day from raw water containing 300 ppm TDS by improved solar still. The use of solar desalination device would help in conservation of conventional fuels, such as firewood, cow dung cake and agricultural waste in rural areas of India. Conservation of firewood helps in preserving the ecosystems and cow dung cake could be used as fertilizer, which could help increase the agricultural production. The economic evaluation of the vermiculite-cement type solar desalination device revealed that high value of IRR (151 per cent) and low value of payback period (0.65 Years) make the unit very cost efficient. The economic attributes of the system revealed its economic viability. Moreover, the use of this device would result in the reduction of the release of CO_2 to the environment. The solar desalination unit will overcome the problem of corrosion associated with metallic solar still. In addition, there is a wide scale adoption of distilled water in dispensaries, laboratories, batteries etc.

Fig. 8: Solar Desalination Devices Made of Vermiculite-Cement Plastered Material

Conclusion

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.