Development and Dissemination of Solar Drying Systems in Nepal: Problems and Prospects

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NEPAL

ABSTRACT

Dried foods are very popular in Nepal. They are consumed in different forms such as snacks, soups, boiled vegetables, curries, desserts, and chutneys. Recently dried agricultural products such as spices, beverages, and medicinal plants have found greater demand in the market. New efforts are being made to meet this demand and to maintain the quality of the products.

In this paper, the need of food conservation in the context of Nepalese socio-economic condition and the importance of dried foods for livelihood have been highlighted. Techniques conventionally used to produce dried products are briefly described. Efforts have been made to develop and disseminate improved solar drying systems and the achievements accomplished so far are presented. The impact of government policy and the development works on local socio-economy has been assessed. Prospects of solar dryers in Nepal under various aspects have been reviewed. Barriers yet to be overcome and efforts still to be made to promote solar drying systems in a wider scale have been identified. Works carried out so far and the results obtained have given hope towards the upliftment of national socio-economy.

1. INTRODUCTION

Nepal is a small land-locked country located between India and China. Over 80% of the country's land mass is rugged hill (65%) or mountain terrain (18%). The hilly region lies between a small part of plain area in the south and high mountains in the north. Only 10% of its area is suitable for cultivation [1]. These unique geographical and topographical features are some of the reasons for the country's poor physical infrastructure and socio-economy. The entire nation depends upon subsistence agriculture whose development is so slow and unable to cope with the population growth rate. As a result, 38% of the total population already lies below the poverty line. This situation is aggravated due to the huge agricultural loss at the post-harvest stage. Traditional techniques being used for several decades or centuries have definitely reduced this loss to a certain extent, but it still stands at 20% to 30% which is quite alarming [2]. It is increasingly felt that appropriate conservation technologies be introduced into the country with the aim of reducing loss and improving the socio-economy of the country. This automatically calls for an in-depth study of the traditional conservation technologies available in the country and then develop new ones that are appropriate. Studies in various aspects will also have to be made in order to make these technologies available to and implemented by the users for widescale applications.

2. THE NEED OF CONSERVATION

Conservation has several implications depending upon the techniques to be used and the purpose. In case of Nepal, the primary requirement is to prevent the surplus of fruits and vegetables from being

spoilt through decomposition, so that it can be stored for a longer period of time and then consumed during off-peak season. There are many areas in the country where plenty of these commodities are grown and then partly wasted as well as areas where the demand is high during off-peak season. This is particularly true for the people living in mountain regions. With the introduction of appropriate conservation technologies, people living in these areas could be highly benefitted.

The other important aspect of the technology is the eventual uplifting of local socio-economy through the creation of sustainable market for such value-added agricultural products which may extend beyond fruits and vegetables to cash crops, vegetable seeds, spices, medicinal herbs, etc. All these would have a positive long-term impact not only on the local economy but also on national development.

3. FOOD CONSERVATION TECHNOLOGIES IN NEPAL

3.1 Traditional Methods

The most widely practiced traditional food conservation technology in Nepal is drying. This is accomplished in various ways. Among them, sun drying is the most popular. In this method the crops are spread in the open field, court yards, balconies, and streets to expose them to the sun and wind. In this way, the moisture content of cereal grains usually at 20% to 24% are brought down to a safe limit of storage (12% to 14%). Occasionally, they are tempered by heaping. Even the surplus vegetables and fruits are sun dried as no other alternatives are available. Certain vegetables such as mustard greens and radish are also preserved by first fermenting them in a crude way and then drying them in the open sun. Food items produced with this technique are quite popular among the native Nepalese. The traditionally sun-dried products of Nepal are listed in Table 1. Other commercially sun-dried products include persimmon, mango leather, cauliflower, radish tuber, radish slices, potato chips, onion, mushrooms, and vegetable seeds.

In fact, food crops (e.g., paddy, maize, millet, wheat and barley), cash crops (e.g., Jute oilseeds, tobacco, tea coffee and pulses), spices (e.g., garlic, ginger, cardamom, turmeric, and chilies), vegetables (e.g., radish, oilseed leaves, and cauliflower), fruits like apples, oranges, and labsi (spondias axillaries Roxb), and medicinal herbs, are all still dried in the open sun.

Table 1 Traditional sun-dried products of Nepal

Gundruk	A fermented sun-dried product from leafy vegetables
Sinke	A fermented sun-dried product from radish
Tama (Bamboo shoot)	A fermented sun-dried product from bamboo shoot
Samjhana	Non-fermented sun-dried ribbons of radish
Arujkunchan	Sun-dried product made from horse gram paste and garden cress
Mula chana	Sun-dried cut radish
Mula bhujia	Sun-dried grated radish
Mula titaura	Sun-dried 'pellets' of mung paste
Masyura	Sun-dried large pellet of mung or horse gram and vegetables like colocosia, radish, squash, cabbage, and garlic leaves.
Labsi candy (Mada)	Sun-dried fruit leather (Hog Plum)
Mango candy (Mada)	Sun-dried fruit leather
Sankatar	Sun-dried acidic/citrus fruit with salt
Dried mango	Sun-dried raw mango pieces
Dried fish	Sun-dried fresh water fish
Sukuti (dried meat)	Sun-dried meat
Marcha	Sun-dried microbiological culture used as a starter for alcoholic fermentation
'Amilo' titaura	Sun-dried 'pellets' or ribbons made from acidic fruit pulp

Fire and smoke drying and shade drying are two other traditional conservation methods which are also widely practiced in Nepal.

Fire and smoke drying is practiced only for a selected few agricultural products such as ginger and cardamom. In this method, the materials to be dried are placed above a traditional kiln.

Shade drying is used for the preservation of apples in mid-western region of Nepal. In this method, sliced apples are hanged on the ceilings inside a cross ventilated room and air at room temperature is passed through them [3].

3.2 Modern Technology

Freezing and drying (electrical and solar) are two major conservation techniques frequently used in Nepal. Freezing techniques are applied to store fresh products for future consumption. Their application, however, is limited only to urban cities for conserving potatoes, tomatoes and few types of fruits like apples and oranges. Electrical drying techniques are used mainly by small commercial enterprises to produce baked and other valuable products. Both of these techniques require substantial amount of electrical energy, which in most cases is not available in the largest part of the country. Thus solar drying has emerged as one of the bright options among the known modern conservation technologies, because it uses natural energy resource (which is abundantly available across the country), is simple, environmental friendly and low in initial cost as well as operation, maintenance and repair costs.

4. SOLAR DRYERS

4.1 Historical Background

Planned development of solar dryers has been introduced in Nepal since the Eighth Five-Year Plan (1980-1985). Emphasis upon its development has however been given only during the Ninth Five Year Plan (1997-2002). Since then the policy for subsidizing the solar dryers through the Alternative Energy Promotion Center (AEPC) was implemented, dissemination works and studies on different aspects of solar dryers were carried out, soft loans were provided, and various organizations had started to be involved in this sector.

4.2 Development of Solar Dryers

The development and uses of solar dryers have been taking place for the last two decades. During this period, some 15 types of solar dryers have been developed and used to dry various agricultural products, mainly on an experimental basis. Their operations are based on either direct drying (cabinet dryer) or indirect solar drying (some versions of rack dryers) or mixed drying (tunnel drying and some other versions of rack drying). These solar dryers can be classified as cabinet type (box type), rack type and tunnel type.

Solar Cabinet Dryer

Solar cabinet dryer is the most simple dryer consisting of a rectangular container. It is insulated at its base and covered with a transparent glass sheet. Holes are drilled through the base to permit entry of fresh ventilating air into the cabinet. Outlet posts are located on the upper parts of the cabinet side and rear panels. The design of this type of solar dryer has been adopted from the one developed at Brace Research Institute, Canada.

Solar Rack Dryer

Solar rack dryer consists of two separate parts: (a) a collector to heat the air from ambient temperature to a desired temperature with the help of solar radiation, and (b) a drying chamber. The commodities to be dried are spread on a number of trays at different layers. Different versions of this dryer are being used currently in the country.

Solar Tunnel Dryer

The tunnel dryer of Marpha, west of Nepal, the only one of this type, consists of a series of collectors and dryers arranged in a particular order. Air is heated in the collector, flows over the products placed in thin layers. The solar collectors are tilted at 20° towards south. The collector panels have two layers of glazing made of UV-resistant polyethylene sheets and blackened aluminum plates as absorbers. Air is pumped into the system by using an electrical blower or a venturi unit attached to the air exit of the dryer.

4.3 RETs in Asia Programme and Development of Improved Solar Dryer

With the exception of tunnel dryers and large rack dryers which are based on forced circulation of air, most of the dryers developed so far run on natural air circulation. Almost all of them were designed, developed and run in a haphazard way without any strong theoretical basis. Practically no information was available in the country on the existing solar drying systems, their performance and uses. No records were available on the solar dryers, which were installed at some places under various programs. Except for a solar tunnel dryer installed at Marpha in Mustang district, west of Nepal, no other prototype solar dryer had undergone any kind of test. In other words no systematic steps were taken at all to develop and promote the solar dryers during the two decades. The entire development scenario of solar dryers in Nepal, however, changed drastically once the Renewable Energy Technologies (RETs) in Asia Programme was established in 1997. Through this program, a number of activities have been carried out which resulted in the development of four specific types of solar dryers (cabinet, rack, tunnel and hybrid). These dryers are shown in Figs. 1 to 4.

Figure 1 shows the latest design of a cabinet dryer with a capacity of drying 2 kg of ginger equivalent. Figure 2 shows the latest design of a solar rack dryer with a drying capacity of 10 kg of ginger equivalent, while Figs. 3 and 4 show the latest design of a solar tunnel dryer and the design of solar/biomass hybrid rack dryer, respectively.

As compared to the old design, the improved solar cabinet dryer has a chimney above the drying chamber as an extra component to enhance air circulation. Circulation of air had always been a problem in the old design, where air circulation is achieved through the holes put along the upper parts of the side plates and rare plates of the drying chamber. The performance of the new cabinet dryer is shown in Fig. 5 which includes the temperature profile, variation of solar insolation and relative humidity.

For solar rack dryer, the new design has a solar radiation collector cum heat radiator as an extra component above the drying chamber used primarily to circulate the air more easily by raising the temperature of the moist air hanging over the top of the drying chamber and speeding up the drying rate of the material on the uppermost tray. This has resulted in reduced drying time and better quality of dried products [4]. The performance of the solar rack dryer is shown in Fig. 6 which includes the temperature profile, air flow rate, solar radiation on the horizontal surface, and relative humidity of ambient air.

For tunnel dryer, the new design has been made much simpler and cheaper to cope with the consumers' demand. Details are given in a study by Joshi and Shrestha [5]. Figure 7 shows that the overall performance of the new solar tunnel dryer is quite satisfactory for drying almost all kinds of fruits and vegetables under favorable weather conditions.

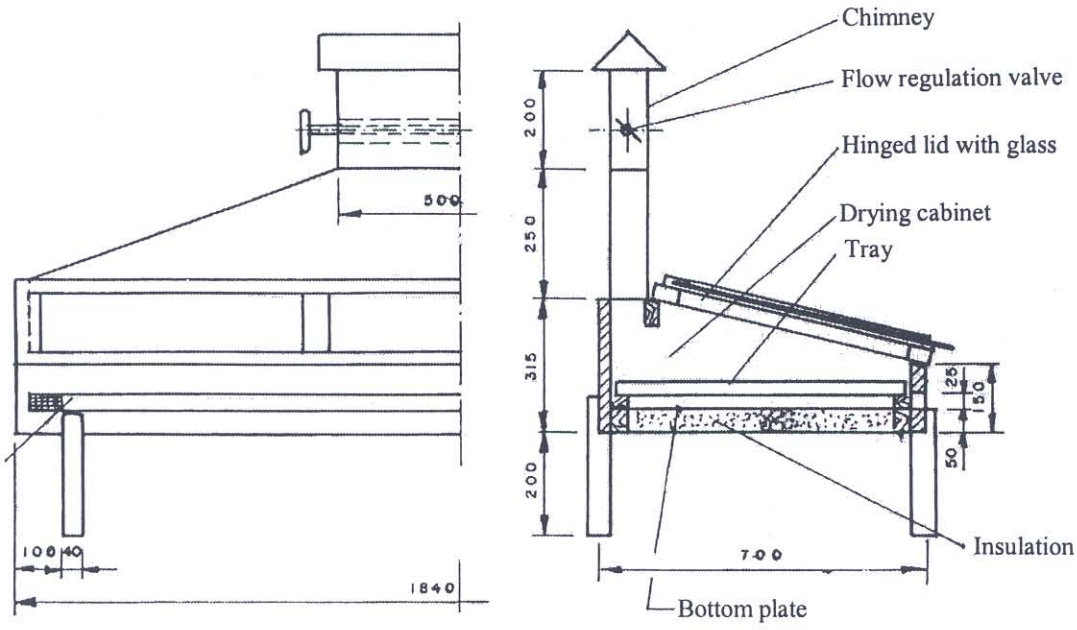


Fig. 1 Improved solar cabinet dryer

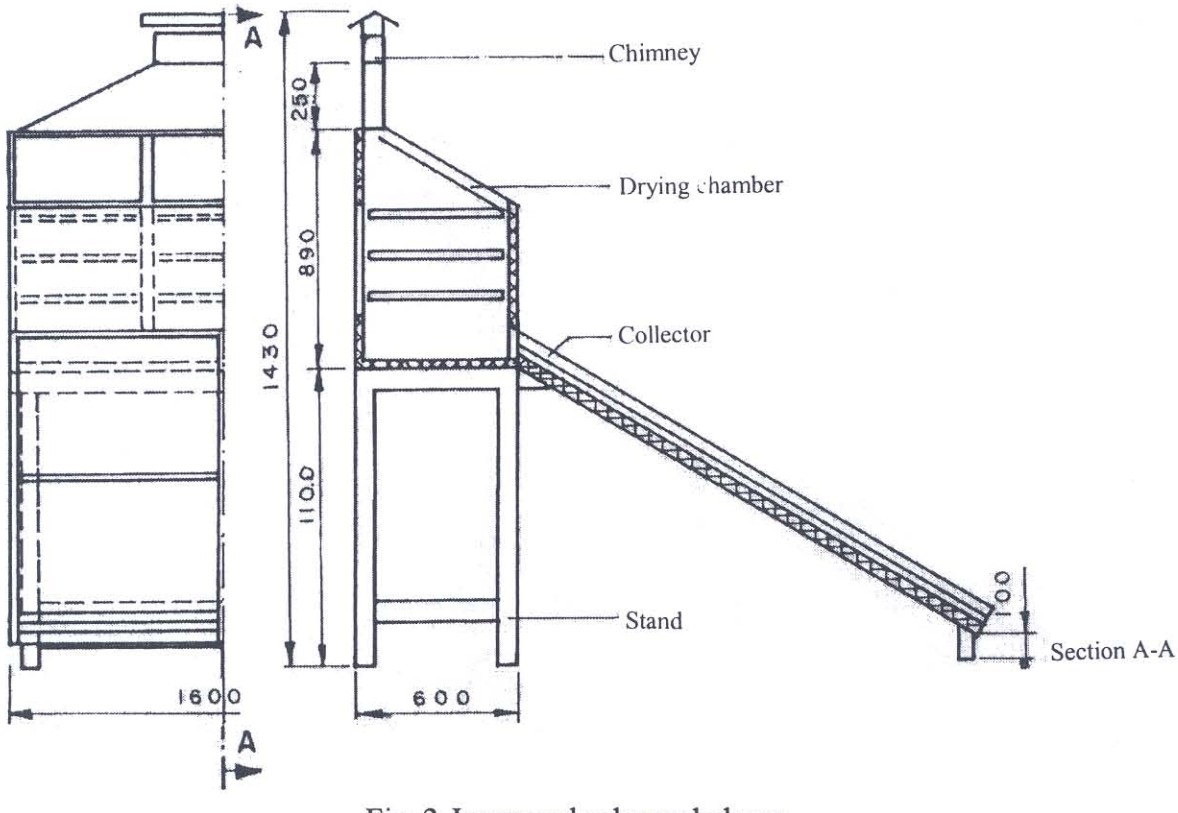


Fig. 2 Improved solar rack dryer

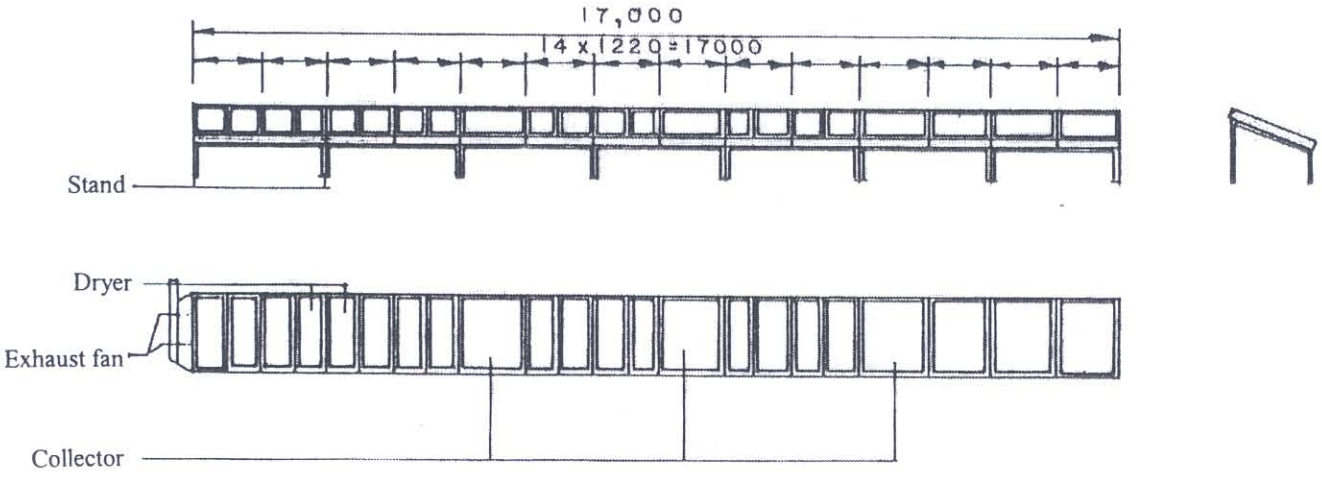


Fig. 3 Improved solar tunnel dryer

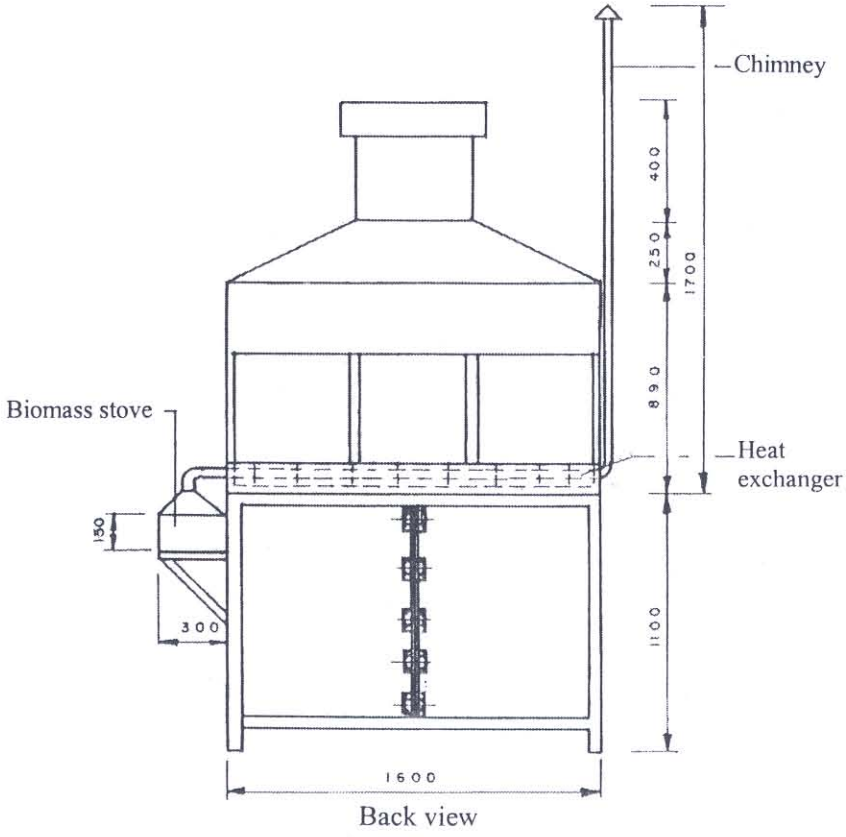
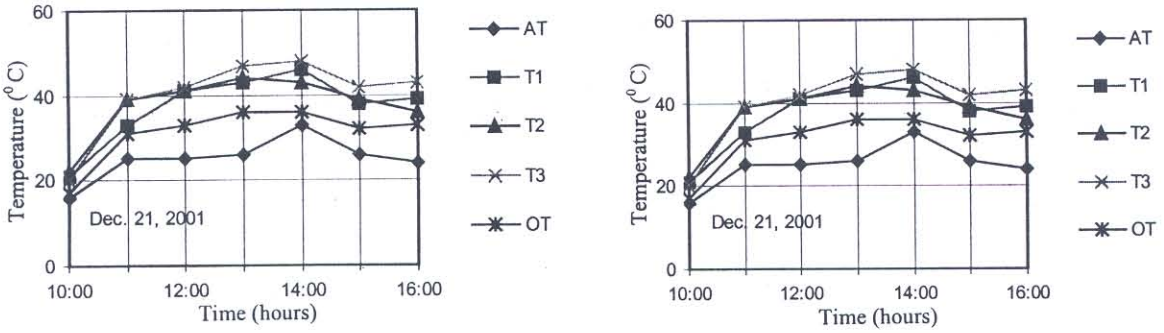
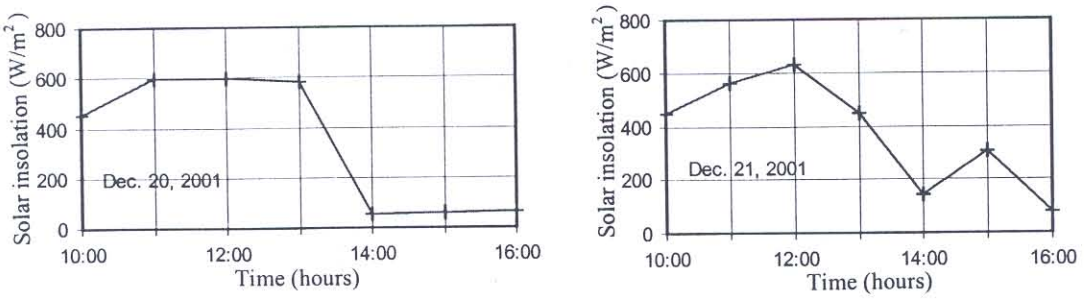


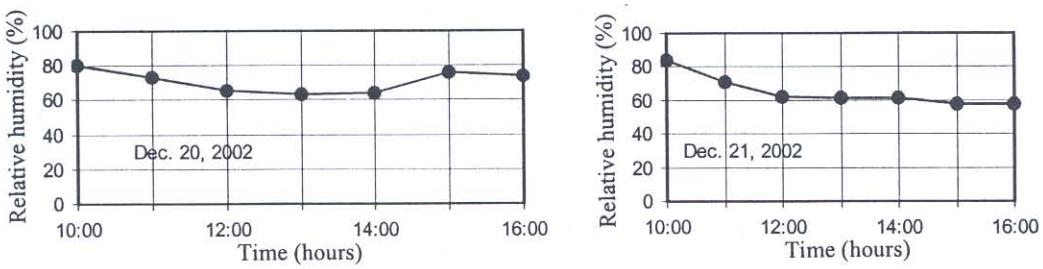
Fig. 4 Hybrid solar/biomass rack dryer



Temperature profile of solar cabinet dryer



Variation of solar insolation



Variation of relative humidity

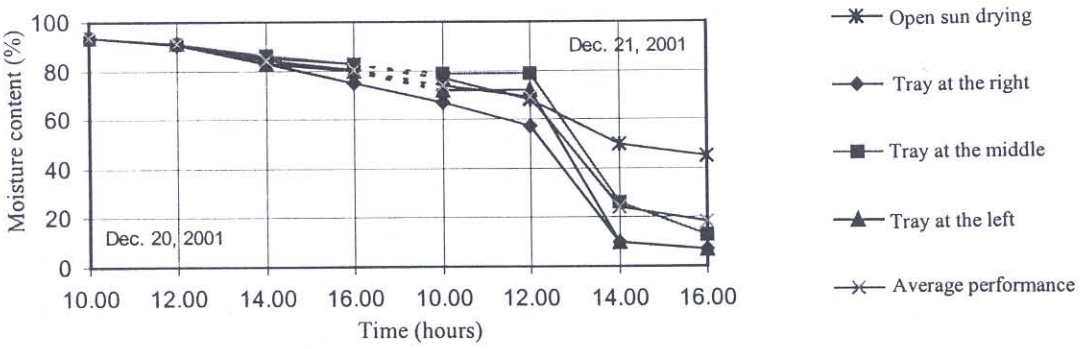
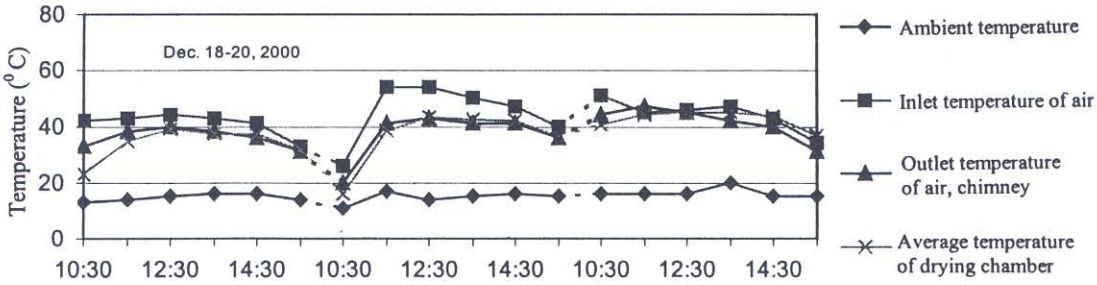
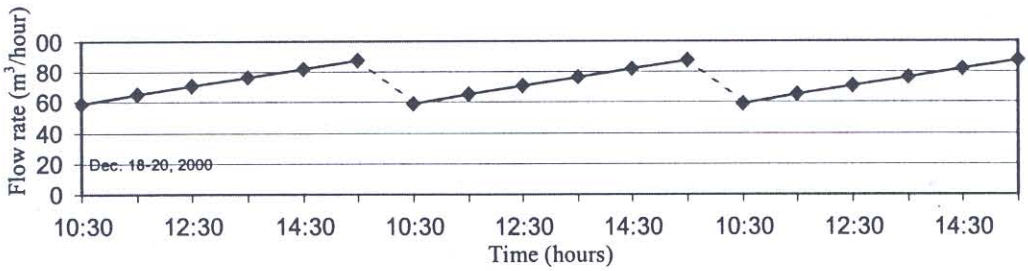


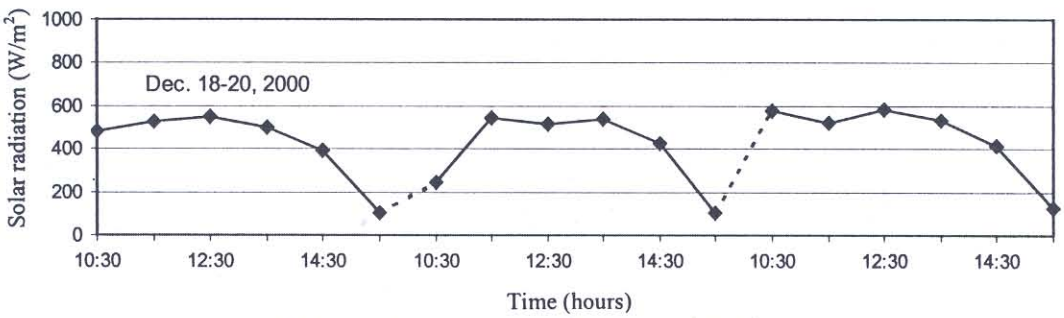
Fig. 5 Performance of solar cabinet dryer with radish



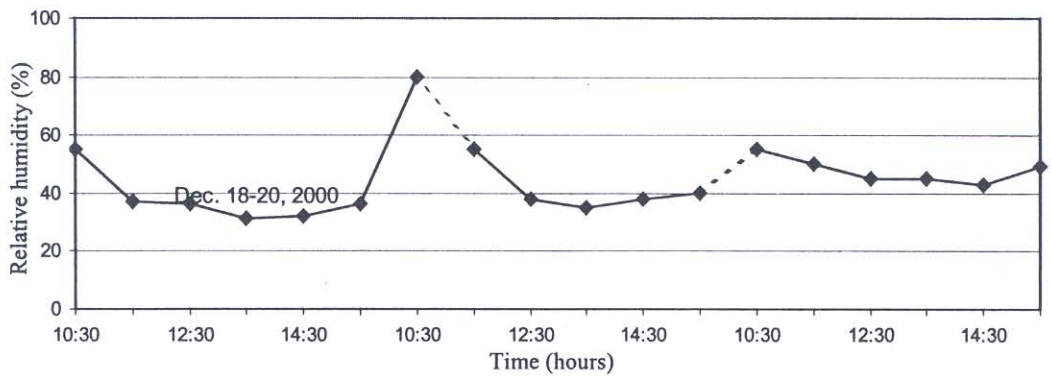
Temperature profile of solar rack dryer



Flow rate of air



Solar radiation on the horizontal surface



Relative humidity of the ambient air

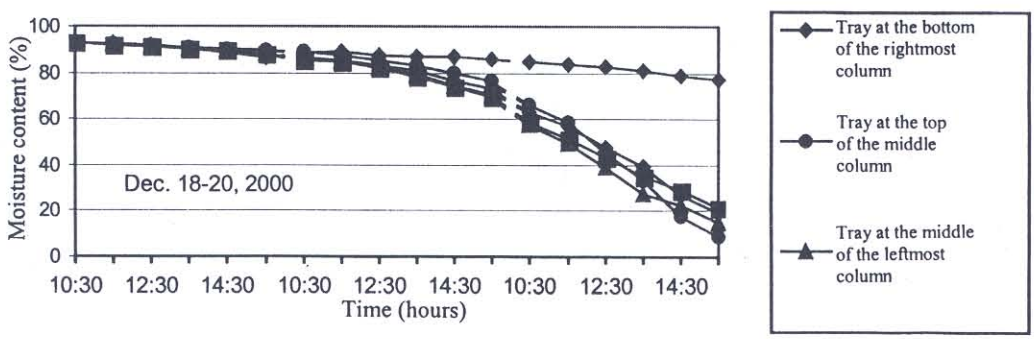
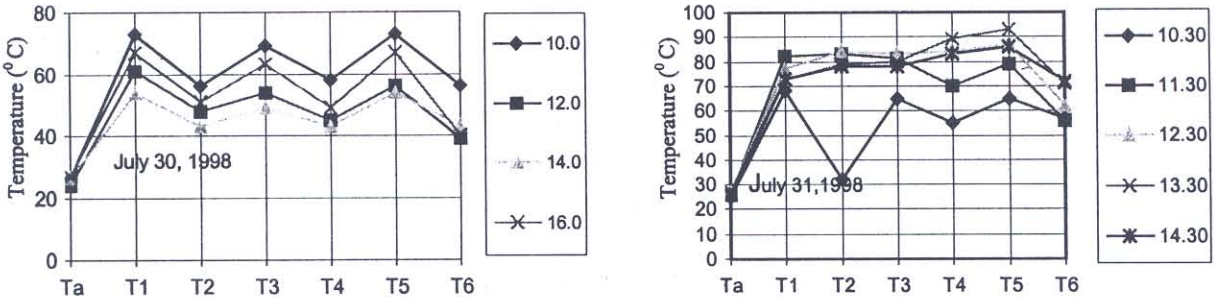
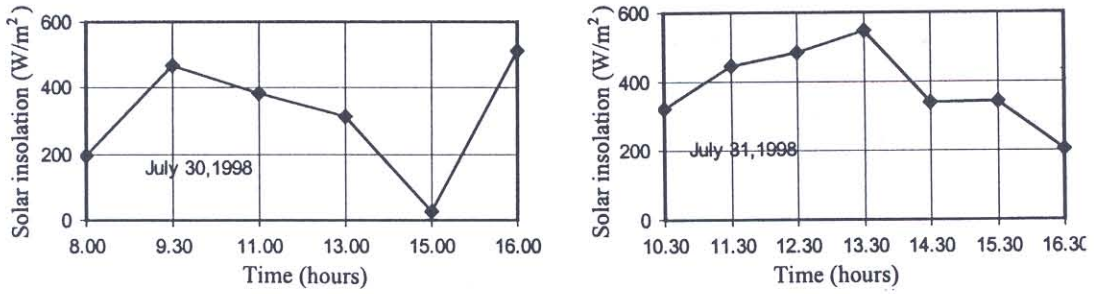


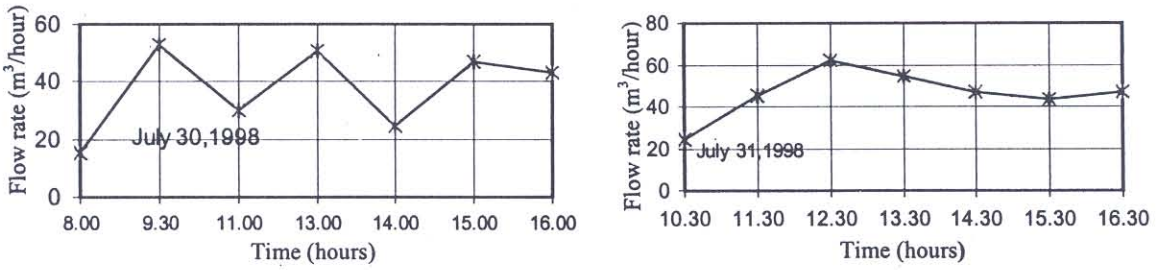
Fig. 6 Performance of solar rack dryer



Temperature distribution inside the solar tunnel dryer



Variation of solar insolation



Variation of airflow through the solar tunnel dryer

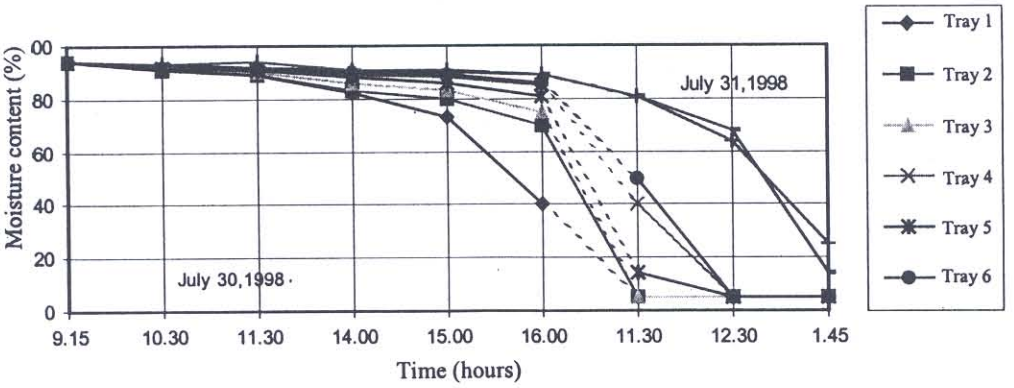


Fig. 7 Performance of solar tunnel dryer with radish

The solar/biomass hybrid rack dryer is in principle a combination of solar rack dryer and a back-up system run with a biomass source like fuelwood or briquettes.

The performance of the solar/biomass hybrid dryer is shown in Fig. 8. Although the drying rate for the materials lying on different tray varies, this type of dryer can be used to dry the products in unfavorable weather conditions [6].

All dryers mentioned in this paper, particularly the solar tunnel dryers, are in extensive use for drying various products for domestic and commercial purposes, whereas the dryers of old designs are hardly in use. This shows that the new dryer designs are better suited to meet the consumer's demand.

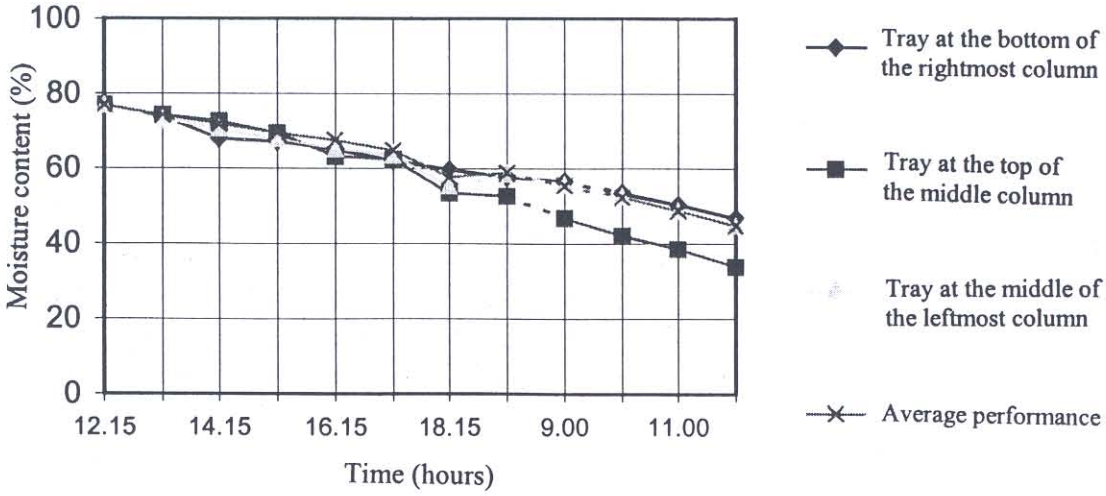


Fig. 8 Performance of hybrid solar/biomass rack dryer

5. MARKET POTENTIAL OF DRIED PRODUCTS

5.1 Internal Market

Dried fruits, either in ordinary form or mixed with some ingredients, are highly popular in Nepal. Similarly some fermented dried vegetables (Gundruk sinke, Tama) are widely used all over the country in form of cooked vegetables, soups and chutneys. Likewise, dried spices and medicinal herbs are also extensively used in Nepal for preparing routine meals and medicines, respectively. Due to recent changes in the lifestyle and work pattern, women now find difficulty in producing traditionally sun-dried products in the urban areas. This situation allows for marketing of traditional food products from rural areas to urban and semi-urban areas. The growing number of dried food shops in almost every corner of market areas is an indication of their popularity among the native consumers. Lately, trekkers and tourists have become the main consumers of dried fruits, which are processed in solar dryers. Solar dried products, e.g., apple slice, apricots, prunes and mangoes are heavily sold in the department stores of Kathmandu and other big cities, which cater to the needs of foreigners and wealthy people. Besides fruits, some entrepreneurs have also started promoting sales of solar dried tomatoes, ginger powder, garlic powder and turmeric powder.

Dried products are extensively used in hotels and restaurants. Dried apples, apricots, grapes, mushrooms, bamboo shoots and even gundruk (fermented dried leafy vegetables) are commonly used for making apple pie, soups, cakes and mixed vegetables. The consumers' demand for such dried products have increased in recent years [7].

5.2 External Market

Several sun-dried products, e.g., dried herbs, dried ginger, dried turmeric, dried cinnamon, dried vegetable seeds, cardamom and tea are exported to India. Table 2 shows the quantity of products exported annually.

Some vegetable seeds are also exported to Bangladesh and Pakistan. Dried mushrooms, the wild exotic varieties from remote mountains, have also found market in India and England.

At present, the marketing channels for the dried products are farmers, small traders and retailers. If solar dried products could be produced in larger quantity and the marketing channels enlarged, it can be assumed that they would easily find their way into the international market.

Table 2 Sun-dried products exported to India [8]

Dried product/year (MT)	1993-94	1994-95	1995-96	1996-97	1997-98
Dried herbs	28100	41700	40500	52600	43700
Dried ginger	23100	76900	47200	46500	36100
Dried turmeric	-	200	1100	2300	4000
Dried cinnamon	8900	3700	5800	10100	2500
Dried vegetable seeds	-	700	2300	2300	400
Total	50100	123200	96900	113800	96900

6. DISSEMINATION OF SOLAR DRYING SYSTEMS

Dissemination of solar drying systems within the country and abroad was carried out by the Research Center for Applied Science and Technology (RECAST) under the RETs in Asia Programme financed by the Swedish International Development Co-operation Agency (Sida) and coordinated by the Asian Institute of Technology (AIT), Thailand. The program was aimed mainly at creating awareness on the importance of solar drying systems among all the parties concerned and familiarizing them with the socio-economic benefits of the systems, so that they are encouraged to make their individual contributions by taking appropriate measures towards the promotion of these systems. In order to achieve the objectives, seminars and conferences were held at national, regional and international levels; the systems were displayed in exhibitions; films were broadcast through national electronic media; brochures, both in native and foreign languages, were circulated; posters were distributed; and a book on the entire development works of solar drying systems in Nepal was published.

Likewise, in order to generate skilled human resources, a series of training programs were organized for the manufacturers and operators of solar drying systems, based on the do-it-yourself manuals, prepared for this purpose. Similarly, demonstration units were installed at various parts of the country to boost awareness of the people on the systems.

7. GOVERNMENT POLICY

The development of solar dryers was, for the first time, given due consideration by the government in the Ninth Five-Year Plan (1997-2002). The plan clearly accepted the possibility of income generation for the rural people through the promotion of solar dryers. It also stressed that the establishment of solar dryers would help protect the environment. On this basis, the government introduced the policy of subsidizing the dryers' costs by up to 75% and providing bank loans to the women's group at low interest rates. In order to promote all forms of alternative energy technologies including solar dryers, it created an autonomous body called the Alternate Energy Promotion Centre (AEPC) under the Ministry of Science and Technology (MOST).

8. PROMOTIONAL ACTIVITIES

Along with the Research Center for Applied Science and Technology (RECAST) several government, non-government and private organizations are involved in the promotion of solar dryers. Details of some of the major organizations and the type of solar dryers being promoted are shown in Table 3. Similarly details of solar dryers installed until 1998-99 are listed in Table 4. International non-government organizations (INGOs), e.g., German Technical Cooperation (GTZ), IUCN, Save the Children, U.S.A., (SC/US), Helen Keller International (HKI), and the International Center for Integrated Mountain Development (ICIMOD), provided funding to promote some of the solar dryers listed in Table 4. Details of solar dryers installed by RECAST under the RETs in Asia Programme are listed in Table 5.

AEPC created a substantial demand on solar dryers by canalizing the government's subsidy program. In order to meet this growing demand, it has qualified some non-government organizations. Financing institutions like Agricultural Development Bank of Nepal (ADB/N) initiated program for providing credit to the users and all these promotional activities were strongly supported by the research and development activities of various faculties under Tribhuvan University, e.g., Institute of Engineering and RECAST.

9. ACHIEVEMENTS

The changes brought about by the solar drying program in the last five years are as follows:

- A data bank is currently available on solar drying systems installed at various parts of the country. The information available include solar dryer types, dimensions, number, manufacturers and users, applications, construction materials, costs, and performance.
- Design details of most suitable solar drying systems that were identified, developed, tested and demonstrated are currently available from RECAST.
- Several local manufacturers have been trained for the fabrication of solar drying systems.
- Information on potential products for solar drying and the markets for the commercialization of solar drying systems are available for use.
- Training materials for manufacturers and operators of solar drying systems have been published as well as materials for technology dissemination .
- A number of key players and stakeholders are well-informed of the importance of solar drying systems in the national development context.
- Institutional capability of RECAST has been strengthened to a great extent through the enhancement of its R&D infrastructure, trained research staff, and skilled management.
- The government has started implementing its subsidy policy for the widescale promotion of solar dryers.
- Separate studies have been initiated by the government on various aspects of solar drying systems.

10. SOCIO-ECONOMIC IMPACT

Since the technology is still at initial stage, dissemination works carried out so far are still nominal, and the size and number of dryers installed to date are too small. It is early to quantify the impacts of solar drying systems on the socio-economy of the country. However:

- Hopes have emerged among the users of solar tunnel dryers, as these have been found economically beneficial for them.
- Visible awareness among the people on the usefulness and advantages of solar drying systems over traditional methods has been created.
- A considerable number of people have been trained and its effect has been seen in the growing

Table 3 Organizations involved in solar drying systems

Name of Organization	Type Of Organization	Major Activities in Solar Drying System	Results of the Activities	Future Programs
Research Centre for Applied Science and Technology (RECAST)	Academic	R&D training, dissemination	Four types of solar dryers developed and a few several manufacturers/operators received training, awareness of the type of technologies, their uses and benefits. Publications, institutional capability strengthened.	Continuation of adaptive research, commissioning of drying system packages, monitoring of drying systems, conducting training programs, preparation of dissemination materials, conducting workshops, seminars, publication, etc.
Alternative Energy Promotion Centre (AEPC)	Government	Provision of subsidies, small study grants	A number of solar dryers subsidized by AEPC are generating income	Continuation of subsidy policy and provision of grants
Centre for Rural Technology (CRT)	Non-governmental organization	Organization of awareness program supply of one- and two-storey solar cabinet dryers, training	Installation and operation of over 20 solar dryers in rural areas and about the same number in Kathmandu valley. Over 50 people (mostly women) are trained to operate solar dryers	Continuation of regular programs as per need and demand. Solar dried foods have become available in the market, new employment opportunities created, income generated
Intermediate Technology Development Group (ITDG)	International non-governmental organization	Development and promotion of simple types of solar dryers e.g, sasto dryers, low cost wooden chest tray dryer, bamboo tray dryer, goomose type dryer, portable table dryer and convertible table type dryer (Bajracharya [9])	People's confidence in the use of solar dryers are strengthened, initiation of industrial food procurement in some villages, positive implications on gender and marginalized groups.	Future programs are available from ITDE
LOTUS (P) Ltd.	Private company	Manufacturing, installation, operation and training	Two rack type solar dryers for drying surplus vegetables installed in Kathmandu valley	Continuation of programs
Sun Works Nepal	Private company	Manufacturing, installation, operation and training	Hundreds of solar cabinet dryers (small and large) and 10 unit racks type dryers fabricated	Continuation of manufacturing of cabinet and rack type solar dryers and development of solar hand-made paper dryers
Chaitya Metal Works	Private company	Manufacturing	Cabinet type and rack type solar dryers fabricated	
Solar Udyog (Ltd)	Private company	Manufacturing and installation	12 cabinet type and 12 rack type solar dryers fabricated	Continuation of manufacturing and installation on demand
Balaju Technical Training Centre (BTTC)	Public company	Manufacturing and training	Fabrication of and training in solar rack dryer	Manufacturing and training
Bira Furniture	Private company	Manufacturing	A few dryers fabricated	
Centre for Energy and Environment (CEE)	Non-governmental organization	R&D training	Development of a hybrid solar/biogas rack dryer, trained local people on fixed type stone / mud dryer and double storey cabinet dryer	Continuation of training, launching of awareness programs, standardization of food drying processes
Solar Appliances Industries (SAI)	Private company	Manufacturing, installation, operation of and training in solar tunnel dryer and marketing of dried products	Marketed solar dried ginger and garlic powder, trained local people to operate the dryers	

Table 4 Details of dryers located in different districts of Nepal

District	Type of Solar Dryer	No. of Units	Size	Total Collector Area	Remarks
Mustang	Tunnel type (built by TU Munich) Marpha	1	24m x 1.5m	36 m^2	Used for drying fruits (mostly apple)
	Tunnel type (Mustang Agro Ind. Tukhe)	1	6m x1.2m	7.2 m^2	Not in use at present
	Cabinet type (Hotel) Marpha	2	1.8m x 0.8m	3 m^2	Mostly used for apple drying
	Box type (locally built) in many villages of Mustang	Approx. 750	1m x 0.5m to 1.5m x 0.4m	450 m^2 approx.	Almost all the apple growers of Mustang have one or many sets of this type of dryers. It is estimated that about 25% (750 households) of the total households in Mustang district have this type of solar dryer
Humla	Box type	4	NA	NA	Some apple growers use this to dry apple
Pokhara	Cabinet type (agriculture farm)	NA	NA	NA	Not in use at present
	Box type (locally built)				
Lamjung	Box type	1	NA	NA	Promoted with subsidy by AEPC
Kathmandu	Tunnel type (HAMCOL) Kathmandu	1	6m x 1.2m	7.2 m^2	Used for nugget drying
	Tunnel type (Women's Self Help Group), Kathmandu	1	16.8m x 1.5m	16 m^2	RECAST/AIT/SIDA (experimental stage, developed under the South Asia Renewable Energy Project). Used for nugget drying
	Tunnel type (Thankot Mahila Samuha), Kathmandu	1	16.8m x 1.5m	16 m^2	RECAST/AIT/SIDA (experimental stage, developed under the South Asia Renewable Energy Project with Swiss funding). Used for nugget, fruit and vegetables drying
	Sasto solar dryer (Daxinkali Gundruk Samuha), Daxinkali	1	1m x 2m	2 m^2	Promoted by ITDG Nepal Under Agro – Processing Programme. Mainly used for Gundruk Drying
	Cabinet type (different users) Kathmandu	19	NA	NA	12 sets promoted with subsidy from AEPC and 7 sets by different organizations and individuals
	Box type (different users) Kathmandu	2	NA	NA	Promoted with subsidy from AEPC
Lalitpur	Cabinet type (different users) Lalitpur	3	NA	NA	Promoted with subsidy from AEPC
	Box type (different users) Lalitpur	3	NA	NA	Promoted with subsidy from AEPC
Bhaktapur	Cabinet type (different users) Bhaktapur	9	NA	NA	Promoted with subsidy from AEPC
Kabre	Cabinet type (different users) Lalitpur	2	NA		1set promoted with subsidy from AEPC–(processing) 1by NGO (not in use).
	Sasto solar dryer (Women's group of WHSH) Baluwa VDC of Kavre	2	1m x 2m	2 m^2	Promoted by ITDG Nepal under Agro-Processing Programme. Mainly used for Gundruk drying
	Low-cost wooden chest tray dryer (Sanga Lapsi processors group)	1			Promoted by ITDG Nepal under Agro-Processing programme. Mainly used for drying Lapsi candy.
Ramechhap	Box type	1	NA	NA	Promoted with subsidy by AEPC
Lumbini	Box type	1	NA	6 m^2	Not in use
Nawalparasi	Box type	1	NA	NA	Promoted with subsidy by AEPC
Chitwan	Tunnel Type (community -based) Kailashnagar	2	12m x 1.2m	24 m^2	Promoted by ITDG Nepal under Agro-Processing Programme. Mainly used for vegetable drying (the dryer was constructed using local by available material, i.e., mud and brick)
	Sasto solar dryer (for Chepang community at Wasbang village of Lothar VDC)	1	1m x 2 m	2 m^2	Promoted by ITDG Nepal under Agro-Processing Programme. Mainly used for vegetable drying (the dryer was constructed using locally available material, i.e., mud and brick)
	Cabinet Type	1	NA	NA	Promoted with subsidy from AEPC
Sarlahi	Cabinet Type	2	NA	NA	Promoted with subsidy from AEPC
Morang	Tunnel type Biratnagar	10	8m x 1.2m	16 m^2	1set promoted with subsidy from AEPC. One by private sector
Solukhumbu	Improved solar rack dryer	10		1 m^2	Promoted by CRT with the help of WWF in WWF supported FUGs in Khumbu and Pharak region
Siraha	Solar cabinet dryer	10			Promoted by CRT with the help of Save the Children Siraha and Helen Killer International (HKI)
Makawanpur	Solar rack dryer at one of the users house at Palung, Shikharkot VDC	1	NA	NA	Test experiment provided by RECAST

Table 5 Details of solar dryer installation under RETs in Asia Programme

Name of Installation	Responsible Individual/Institution	Type of Dryer	Materials Dried
Hile VDC, Kakani, Kathmandu	Shyam Bhakta Shrestha, Hile VDC	SRD	Fermented radish
Palung VDC 9, Makawanpur	Palung VDC, Palung	SRD	Cauliflower, cabbage, radish, potatoes
Barha Banjyang, VDC-1 Thankot	Dharma Das Amatya, Bijuli Bazaar, Kathmandu	STD	Strawberry, membin (Labsi), cauliflower, mushroom, gooseberry, carrot, etc.
Gokarna VDC-9, Gokarna, Kathmandu	Women Self Help Society	STD	Masyaura Gundruk (fermented vegetable), radish, cauliflower, cabbage, potatoes
Banepa Municipality Kabhre District	Ayurved Society Banepa	SCD	Herbs
Khopasi VDC, Kabhre District	Sericulture Development Division	SCD	Cocoon
Madan Pokhara VDC-9, Palpa	Mr. Nagendra Pandey	ISRD	Ginger, vegetables and coffee beans
Madan Pokhara, Palpa	Mr. Madan Ghimire	ISCD	Vegetables and coffee bean
Malekhu, Dhading	Mr. Prakash Kunwar Chhetry	SBHRD	Fish
Babar Mahal , Kathmandu	Department of Food and Quality Control	ISRD	
Gokarna, Kathmandu		ISRD	Demonstration
Kirtipur, Kathmandu	RECAST	ISCD	
Kirtipur, Kathmandu	RECAST	ISTD	
Kirtipur, Kathmandu	RECAST	ISTD	

Types of dryer:
ISCD - Improved Solar Cabinet Dryer
ISRD - Improved Solar Rack Dryer
ISTD - Improved Solar Tunnel Dryer
SBHRD- Solar Biomass Hybrid Rack Dryer

consumption of solar-dried products in the market. This has positively affected the livelihood of farmers, traders, entrepreneurs and laborers.

- Disadvantaged men and women have found opportunities for employment.
- Even the old and weak women can now easily dry their commodities which was not possible using the traditional open sun drying.
- Marginalized groups of farmers having very small plots of land can now use the drying systems to dry and store their dried products for consumption during off-peak season. Thus the introduction of solar drying technology among the poor farmers have become an instrument in poverty alleviation.

11. PROBLEMS AND PROSPECTS

11.1 Problems

Some of the problems presently encountered are the exorbitant costs of some of the existing devices which are unaffordable to small farmers, lack of knowledge and information among the general public on the applications and uses of solar dryers, absence of government's widescale promotional and dissemination programs, lack of adequate reliable data and climatic records across the country, and the need of multi-disciplinary knowledge in the design, manufacturing and operation of solar dryers.

Development-Related Problems

In the absence of experience on the development of solar drying technology in Nepal, all three types of solar dryers, e.g., cabinet, rack and tunnel, were initially adapted from the ones already existing in the country and then gradually converted into improved designs to make them technically viable and suitable for local conditions.

The main problems were related with the design. The problems and the corrective measures taken to address them are described in Table 6.

Table 6 Problems of existing solar dryer and the corrective measures adopted in improved designs

Type of Dryer	Existing Design	Problems	Consequences	Measures adopted
Cabinet	Direct drying, single glazing, not preheated air, handling of materials by opening the complete shutter, air circulation through the holes on the rear sides, natural air circulation, 20^0 inclination, 0.36 m^2 drying area, about 2 kg fresh ginger drying capacity, wood, steel section, aluminium sheets, glass sheets and glass wool as construction materials. Cost: NRs. 2,000 (1984) (about US$ 30.00)	- Decolorization of dried products - Low inside temperature - Unsuitable for UV-sensitive materials - Heat loss in loading and unloading	- Dried products look unhygienic and unappetizing - Slow dehumidification - Slow drying	Single glazing, handling of materials by pulling the drawer from the back, air circulation through chimney at the top, 0.98m^2 drying area, 5.5 kg fresh ginger drying capacity. Wood, steel section, aluminium sheets, glass sheets and glass wool, as construction materials. Cost: NRs. 4,000 (about US$ 62.00)
Rack	360.70 cm collector size, single glazing 160 cm height of stand, single shutter, 8 no. of racks, 8 no. of trays, 1.44 m^2 tray area, 0.3m^3 drying chamber not convenient to work with 7 kg of fresh ginger, force ventilation with two d.c. operated fans, woods, steel section sheets, glass sheets and glass wool as construction materials. Cost: NRs. 22,000 (1993) (about US $343)	- Single door in the rack - Drying chamber not matching with collector area - Greater loss of heat through glazing	- Heat loss, slow drying - Drying chamber too high and inconvenient to work with - Rise in collector temperature, too low	200.160 cm collector size, 110 cm height of stand, tripple shutter, 3 no. of racks, 9 no. of trays, 2.1 m^2 tray area, convenient to work with 12 kg of fresh ginger, natural air circulation, wood, steel section, aluminium sheets, glass sheets and glass wool as construction materials. Cost: NRs 32,000 (about US $ 500)
Tunnel Dryer	1.5 x 1.22 cm collector size, double glazing, 1.3 m height of stand, single shutter, 20m^2 tray area loading /unloading difficult, 100 kg fresh apple, force ventilation with suction type of fan of 1.4 kW with long chimney and venturimeter, wood, steel section, aluminium sheets, plexi glass for dryer and UV-resistant polythene sheets for collector and glass wool as construction material. Cost: NRs. 500,000.00 (1993)	- Fabrication materials frequently damaged and not locally available - Frequent interruption in electricity supply - Suction of sulphur vapor by the pump, fluctuation in supply voltage - Venturi unit not functioning even during windy season - Unsuitable for UV-sensitive materials	- Difficult in immediate maintenance and repair at local level - When suction pump is out of operation, there is increase in inside temperature cracks in glazing - Frequent damage of air suction pump - Chimney only added to the cost of the dryer	1m height of stand, double shutters, 16 m^2 tray area, easy to work with, 70 kg of apple, force ventilation with five D.C. operated fans with solar panel. No exhaust chimney and no venturi unit, wood, steel section, aluminium sheets, glass sheet and glass wool as construction materials. Cost: NRs: 300,000.00 (about US$ 4690.00)

Dissemination-Related Problems

Dissemination of solar drying technologies had been attempted through the installation and operation of demonstration units at various ecological zones of the country; launching exhibitions at various levels; publication of books, booklets, and articles; distribution/circulation of brochures, posters, and news; and showing of documentary films through electronic media.

Inadequate Resources

Efforts to disseminate solar drying systems have created, to some extent, an awareness among people on their availability, uses and benefits. As a result a number of queries and requests were also received from individuals, groups and institutions within the country. Much progress might have been made in the promotion and dissemination of technologies, if all these queries and requests could have been well addressed. But due to the country's difficult topography and poor physical infrastructure as well as RECAST's limited resources in terms of physical facilities, manpower and finance, only a few requests could be responded. The worse part is that not even all of them could be regularly monitored and supported with technical and managerial back-ups, so that only a few units are making satisfactory progress. Additionally the recent political unrest in the country has created many more problems in the dissemination activities, particularly during site identification for demonstration units, their installations and monitoring. The one time distribution of dissemination materials to only a certain number of people and limited publicity of technologies through papers and electronic media were not adequate to disseminate the technology throughout the country. Preparations are therefore being made to address these problems by increasing the skilled manpower through frequent and intensive training programs and undertaking the dissemination campaign in a more vigorous way.

Improper Identification of Demonstration Sites

Careful attention was given in the selection of demonstration sites by developing various criteria, e.g., easy access to the site, good prospect for drying, existence of market for solar-dried products and availability of experienced manpower responsible for the operation and maintenance of drying equipment. Adequate home works were also done before bringing the demonstration units to the sites and providing training to the concerned caretakers of the units. However, the caretakers consisting of community members and government institutions lack commitment. The community members could not cooperate among themselves and the government institutions could not include the technology in their priority list, so that only few units run by private individuals have become successful in providing benefits. The problems encountered during the post-installation period could not be predicted beforehand. As a result, the anticipated multiplier-effect of the successful technology around the demonstration sites was nominal. Furthermore, in spite of the legal agreement, the communities are not allowing RECAST to relocate the units to more appropriate places. Due to this, the resource has remained unutilized and the effects of 0dissemination has declined to a certain extent.

The main reasons behind these problems seem to lie on the lack of adequate experience in such works, and lack of adequate resources and efforts for regular monitoring as well as the socio-political circumstances existing in the country.

Plans are, hence, being formulated to select the future demonstration sites more carefully on the basis of experiences gained so far. In other words, emphasis will be given to individual caretakers and vigorous efforts will be made in regular monitoring of the units and providing all necessary technical and managerial back-ups to the caretakers.

Poor Operation and Maintenance

The primary objective of the demonstration units was to evaluate the socio-technical viability of the solar drying technology for the selected demonstration sites. Hence, these units were fabricated in the metal workshops and brought to the sites, where the caretakers were carefully trained in their operation and maintenance.

During the post-demonstration period, however, these units were neither run nor maintained strictly as per the guidelines described in the operation and maintenance manuals. The result was that the products were not dried satisfactorily leading to reduced interest of the operators in the technology.

The reasons behind the poor operation and maintenance were the lack of adequate knowledge in drying all kinds of products considering their individual physical and chemical characteristics as well as the problem of mobilizing the necessary financial and human resources to procure and maintain/repair the particular components of dryers.

It is planned that these kinds of problems will be sorted out in the future by providing complete packages of technology to individual demonstration sites. They will include all information materials on the particular solar dryers, manuals for their fabrication and operation, drying and storage process for all materials in that particular locality, manual for spare parts and tools for its maintenance as well as audio-visual cassettes showing the complete manufacturing, operation and maintenance process of that particular solar dryer.

11.2 Prospects

Markets for dried agricultural products have always been existing in the country because of traditional food habits of the people. A considerable amount of the products is also being imported to neighboring countries. With the increasing awareness on health, the prospect of the use of solar dryers has increased. Studies have also shown that a number of potential sites do exist in the country where solar drying systems can be profitably used even in small industrial scale. Potential applications of these systems in cocoon drying, hand-made paper drying, drying of medicinal herbs, tea and tobacco leaves have opened new opportunities to the rural people.

This is more so for customers and entrepreneurs living in the urban areas as they have easier and quicker access to all kinds of information resources, technical know-how, outside supports and markets of commercialization. Depending upon their requirements and the type of solar dryers available so far, they can now be procured from the manufacturers or fabricated on their own with the help of existing manuals. For the people in rural areas, the technologies and the materials required for their fabrication, installation, operation, repair and maintenance as well as other technical, managerial and marketing supports are readily available. Manufacturers and entrepreneurs in these areas can well take advantage of these facilities, produce value-added products out of their agricultural, horticultural and forest products to generate additional income, create opportunities for employment, avoid excessive wastages, conserve food for off-peak seasons and protect the environment caused by the excessive use of firewood for drying.

Prospects Based on Current Activities

RECAST is currently involved in RETs in Asia, Phase III Programme. This two-year program includes:

- the commissioning of demonstration packages containing: (a) four different kinds of solar dryers; (b) tools and instruction materials to fabricate, install, operate, maintain and repair the solar dryers; and (c) dissemination materials in form of books, booklets, brochures, posters, audio-video cassettes, and other promotional materials;
- monitoring of solar dryers commissioned so far to identify the barriers to the promotion of solar dryers;

- implementation of identified measures to overcome the selected barriers;
- training of manufacturers and entrepreneurs on the manufacturing and operation of solar dryers;
- publication and distribution of dissemination materials;
- organization of seminars/workshops for users, technicians and policy makers; and
- sending RECAST's own staff abroad to receive training on solar dryers.

Alternative Energy Promotion Centre (AEPC) is presently working on a large-scale solar energy project with a donor country. It involves millions of dollars and is almost at a final stage. This project deals among others with the development, dissemination and promotion of solar dryers. It is expected that these activities would enhance the prospect of solar drying technology to a large extent in Nepal.

Prospects Based on Government Policies

Nepal's government has given its top priority to both the agricultural and renewable energy sector in the Tenth Five-Year Plan (2002-2006). During this period, the government intends to commission 2700 solar dryers in 20 districts across the country [10].

The Ministry of Science and Technology is continuing its subsidy policy. AEPC has been providing small grants for a few applied research and awareness programs to various NGOs.

It is certain that these government policies will encourage the promotion of solar drying technologies in the country.

Prospects Based on Present Trend

Solar dryers were already introduced in Nepal in the mid-1970s when a few cabinet type solar dryers were installed in various parts of the country through RECAST and the Resource Conservation and Utilization Project (RCUP). However, hardly any work was done towards the development and promotion of this technology until RETs in Asia Programme was established in 1997. Under this program and with the policy initiatives taken by the government, the demand of solar dryers in the last five years has increased substantially. In order to meet this demand, the number of solar dryer manufacturers have also increased from two to three 5 years ago, to more than seven at present as shown in Table 3.

With the realization that the solar-dried products are both good in appearance and fully hygienic, their popularity has risen dramatically not only among the native youths but also among the trekkers, tourists, hotels and restaurants. The wide variety of solar-dried products in the department stores and domestic markets are an indication of their growing demand in the country.

In view of solar dryers' potential to generate lucrative income, a few industries in Kathmandu have already started their business in this sector. Also some INGOs have started financing a few solar dryer projects to help the backward and marginalized people in the rural areas.

It is assumed that this trend will continue in the future leading ultimately to a widescale promotion of solar dryers in Nepal.

Prospects Based on Unique Features

Solar dryers have their own characteristic features as far as fabrication, benefits, uses, maintenance and repair are concerned. They can be locally fabricated with mostly locally available materials and locally trained skills. In other words, they can be tailored exactly as per local requirements or modified as and when necessary. Installation, operation, maintenance and repair of solar dryers can also be done locally. With this technology, one can create employment opportunities even for the old and handicapped people and generate income. This is a simple, affordable, acceptable and hence appropriate technology for everyone including the rural poor. As such these features completely differ from other popular solar

devices such as solar water heaters and solar home systems which can neither be locally fabricated, maintained and repaired nor can be affordable to the rural poor. Solar water heaters and solar home systems are being used only as modern facilities by a limited number of people in limited areas of the country and certainly not as a means to create employment opportunities or generate income. Hence, their uses will be limited mainly to urban/semi-urban areas, whereas solar dryers will gradually find their uses all over the country, provided they are appropriately and adequately supported by the concerned institutions.

12. NEED OF FURTHER EFFORTS

Much more efforts in the promotion of solar dryers in Nepal should be undertaken. Some of the efforts that need to be addressed immediately are:

- to fabricate and prepare demonstration packages (e.g., drying equipment, training materials, dissemination models, and measuring instruments);
- to identify local entrepreneurs, manufacturers, users, promoters, traders and financers in the selected regions/sites and provide them adequate skill, knowledge and information;
- to make buyers of the drying systems aware of the subsidy systems and the facility of receiving soft loans from the credit institutions;
- to conduct follow-up studies and identify the barriers to the promotion of solar dryers;
- to make commitment from the government for continued and increased support for long-term solar dryer program; and
- to continue R&D for further development of solar drying systems for wider applications (i.e., to be able to dry other agricultural products besides fruits and vegetables).

13. CONCLUSIONS

From the information that are available on the development and dissemination of solar dryers/ drying systems, the following conclusions can be drawn:

- a wider scope exists for the promotion of solar dryers/drying systems,
- a great deal of achievement has been made to take advantage of the existing scope,
- the techno-socio-economic barriers to widescale promotion of solar dryers/drying systems have to be removed. Government, non-government and private organizations should intensity their efforts to eliminate the barriers.

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15. REFERENCES

[1] Banskota, K. and Sharma, B. 1999. *Pattern of Energy Use in Nepal. Energy Use in Mountain Areas*. Kathmandu: International Centre for Integrated Mountain Development (ICIMOD).

[2] MOA (Ministry of Agriculture). 1997. Progress Report (1980/81 - 1995/96). Post-Harvest Loss

Reduction Division, Department of Agriculture, Lalitpur, Nepal.

[3] Joshi, C.B. 1993. Prospects of Solar Drying of Agricultural Products in Nepal. Technical University of Munich, Germany.

[4] Joshi, C.B. and Pathak, T.P. 2002. Development of a simple modular type solar rack dryer for rural use. In *Proceedings of the International Conference on Renewable Energy for Rural Development*, 19-21, January, 2002, Dhaka, Bangladesh.

[5] Joshi, C.B., and Shrestha, V.M. 1999. Performance evaluation of a modified solar tunnel dryer. In *Proceedings of the Third National Conference on Science and Technology*, March 8-11, 1999, RONAST, Kathmandu, Nepal.

[6] RECAST. 2001. Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme (RETs in Asia) Phase II, Progress Report V, Kathmandu, Nepal.

[7] RECAST. 2002. Renewable Energy Technologies in Asia: A Regional Research and Dissemination Programme (RETs in Asia), Phase II, Final Report, Kathmandu, Nepal.

[8] FNCCI. 1999. *Nepal and the World - A Statistical Profile*. Kathmandu: FNCCI.

[9] Bajracharya, K. 1999. Compendium of Solar Dryer Technology in Nepal. A paper submitted to International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal.