Passive Greenhouse Type Solar Dryers and Their Development

W.W.S. Charters, R.W.G. Macdonald, D.R. Kaye
The University of Melbourne, Australia

Sun Xiaoren
Shanxi Information Institute of Science & Technology, China

ABSTRACT

This paper mainly deals with the development trends of greenhouse type solar dryers in recent years. Several typical installations, which are mainly used for drying agricultural products, are presented. The paper also provides some highlights of allied research subjects.

INTRODUCTION

It is well known that solar drying is important for agricultural products. Statistics show that rain damage, insect infestation and mildew cause approximately 10% loss of all agricultural products. In the Philippines, for instance, the wastage of total dried foodstuff production is about 30%.

Sun-drying has been used for agricultural products since ancient times, however only in recent years have both developed and developing countries paid increasing attention to the use of solar drying. From the proceedings of the last ISES Solar World Congress and also some recent publications on solar drying, it can be seen that work on this topic is increasing, and that solar drying plays an important part in solar energy applications. The greenhouse dryer is one of the main types of solar dryers in use and can be used not only for drying fruits, vegetables, grains, nuts, etc., but also for items such as fur and wood. Experiments show that solar drying can shorten the drying time, raise product quality and improve hygiene [1,2].

Various types of solar dryers have been developed in many countries. They can be divided into direct and indirect dryers, depending on whether the produce being dried is exposed to insolation or not.

Greenhouse dryers are of the direct type, and significant progress on the development of these systems has been made in the last decade. Studies show that they are especially applicable for low temperature drying, which is particularly suited to agricultural products. If the drying temperature is higher than 50°C, the quality of the protein and vitamin in the drying products will be spoiled. Due to their low cost and simple construction, greenhouse dryers are especially attractive to the developing countries. Many have been constructed to demonstrate their performance. These dryers account for a considerable proportion of all solar dryers, particularly in developing countries. For example, in China they make up about 1/3 of all solar dryers.

In this paper, we mainly survey the existing greenhouse type solar dryers, especially the passive ones, and try to find some directions for their future development.

TYPES OF GREENHOUSE DRYERS

A greenhouse type solar dryer looks like an ordinary greenhouse, but is mainly used for drying, where the dried produce itself usually absorbs the sunlight directly.

Greenhouse dryers can be classified as follows:

A. Shape of the collecting area
   1) one-slope dryer,
   2) arch or double-slope dryer.

B. Whether a fan is used or not
   1) passive (no fan),
   2) active (fan is used).

C. Glazing material used
   1) glass dryer,
   2) plastic dryer.

One-Slope Dryers

One-slope dryers are particularly suitable for temperate zones. Various one-slope greenhouse solar dryers have been constructed in different countries, for both different drying conditions and different products.

Figure 1 shows a one-slope solar dryer [3]. This dryer is mainly used in Thailand. It is covered with clear plastic sheet on an inclined bamboo framework. Under the cover there is a layer of burnt rice husks or black plastic film to act as an absorber. The drying chamber is a shallow wooden box, which has perforated metal or bamboo matting as its base. On top of the drying chamber there is a chimney, which draws heated air through the drying chamber. The area of the collector is appropriately 32 m^2 (4.5 m x 7 m), and the drying chamber is about 7 m^2 (1 m x 7 m).

This dryer is used for drying one tonne batches of wet paddy, where it is possible to dry it from 20% moisture to 13% in one or two days. Moisture content of 14% or below is required for storing harvested paddy with minimum losses and quality deterioration. The milling quality and

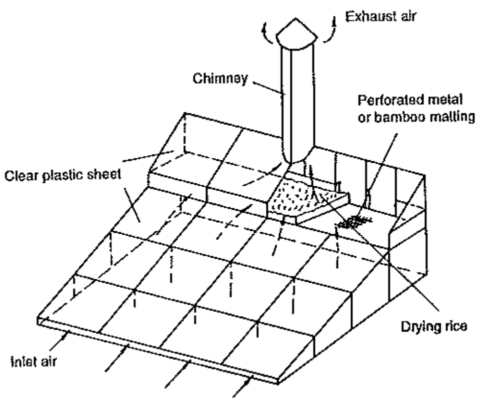

Fig. 1. Solar chimney dryer.

germination of the paddy dried in the dryer have been demonstrated to be superior to those of ordinary sun-dried rice.

This dryer has been designed so that it can be made by the farmer himself, at low cost using locally available materials. Costwise, it was estimated that the "break even" point could be reached after several batches had been dried. Other agricultural products, such as bananas, fish, peanuts, chillies and fruit pastes were successfully dried during the paddy off-season.

The dryer's shortcomings are its relatively high chimney, which is unstable on windy days, and the need to replace its covering plastic sheet, which can be relatively expensive.

China's climate is predominantly temperate, so its greenhouse solar dryers are mainly one-slope dryers facing south. Figure 2 shows the sectional views of a solar dryer [4]. A greenhouse dryer is located at the southern end, and a supplemental drying room is connected to the northern end. In the lower part of the front wall are air inlets, and on the upper back wall there are 8 chimneys. Two rows of windows in the common wall between the greenhouse and the drying room allow air to circulate. This solar dryer is mainly constructed of bricks, cement, iron and glass, so that it will last a long time. It is 30 m long from east to west and 4 m wide from north to south, and is covered with glass. The area of the drying room is 20 m^2 (10 m x 2 m). This drying room can also be used for indirect drying.

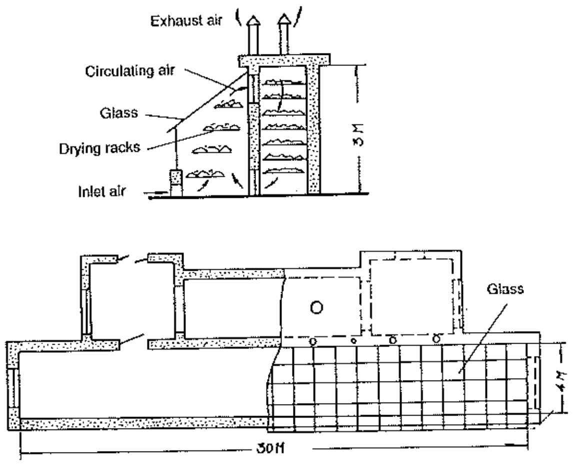

Fig. 2. Cross-sectional and plan views of a Chinese dryer.

Experiments have shown that the moisture content of 5,000 kg of dates can be reduced from 65% to 48% in two days. After two days in the dryer and 7-15 days in the open air, the moisture content of dried chinese dates is below 40%, compared to 45-60 days using traditional methods. Fast drying can also reduce the rate of rot and mildew of the dates. This dryer is also used to dry chillies, day lily, chinese herbs, etc. In winter and early spring it can be used as a nursery. Experiments have shown that the cost investment can be recovered within 3 years.

Similar solar dryers have been built in the USSR for tobacco drying, and also in China for drying fur, fruits, candied fruits, etc. In Yugoslavia, a pilot greenhouse solar dryer is used to dry medicinal plants.

A cabinet solar dryer can also be classified as a greenhouse dryer. It is of simple construction, and consists of a rectangular container, preferably insulated, and covered with a roof of glass or clear plastic sheet. In the base and upper part there are some holes for air circulation. Perforated drying trays are positioned within the cabinet [5].

Considerable work has been carried out to improve it, particularly with respect to construction materials. In developing countries, clay bricks, mud and wattle are also used.

Figure 3 shows a cabinet solar dryer, used in Bangladesh [6], with a floor area of 2.9 m^2 and, depending upon the food being dried, a capacity of 2.5 to 20 kg. The box is made of a 5 cm thick "sandwich" of woven bamboo sheets and rice straws. When the outside air temperature is 35°C, the drying temperature, at noon, is 65° to 75°C. It is mainly used for drying fruits and vegetables.

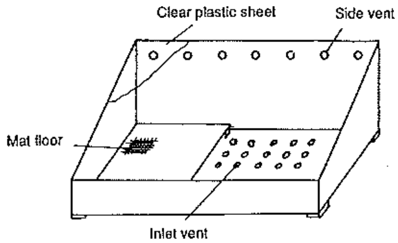

Fig. 3. Cabinet solar dryer.

A cabinet solar dryer can only contain a small quantity of the products to be dried. So it is designed for family use or for high price commodities. It is easy for farmers to operate and lasts for several years.

India has designed another kind of cabinet solar dryer (Fig. 4) [7]. The main frame is made of mild steel angle-iron. The aperture area is approximately 6 m^2. The back and sides are closed with 2.5 cm thick wooden panels which also serve as insulation. Fourteen horizontal trays are arranged in two columns of seven rows. Each tray has a height of 4 cm and measures 35 cm x 90 cm. The air enters through the perforated base of the dryer, and escapes from the top slit.

The dryer has been used for drying carrots. Results show that the removal of moisture per day per square metre of glazing area is 2.3 to 3.7 kg.

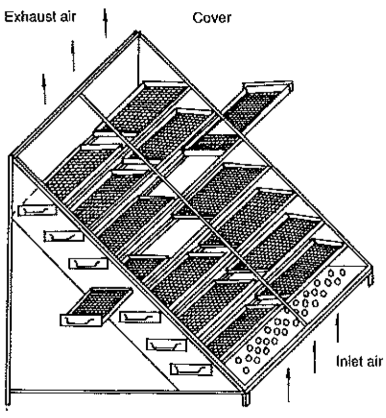

Fig. 4. View of the multi-rack dryer.

Arch Solar Dryers

Arch or double-slope solar dryers especially suit the tropics. A simple one is shown in Fig. 5, the transparent cover reduces the heat losses. On both sides of the arch dryers are holes or slits for the entry of fresh air. The hot humid air escapes by natural convection, out through both ends of the dryers. The drying product is spread on mats or foils, which are put on the ground. This method can reduce drying time, compared with open air drying.

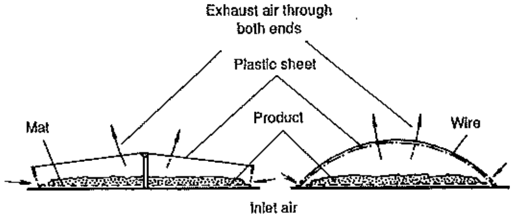

Fig. 5. Simple solar dryer.

In the USA, North Carolina State University has set up an experimental solar greenhouse dryer (Fig. 6) [8]. It consists of an arch shape chamber covered with clear corrugated fibreglass and is 7.7 m wide, 4.0 m high and 8.5 m long. Inside the chamber, there are two cylindrical drying units, each is 2.2 m in diameter, 4.6 m long and has a capacity to hold approximately 3 to 4 tons of peanuts. During drying, the drums rotate and a fan blows atmospheric air into the chamber. The cylindrical surface of the dryer is perforated to permit hot air to enter the drum, and the surface is blackened to act as a solar collector.

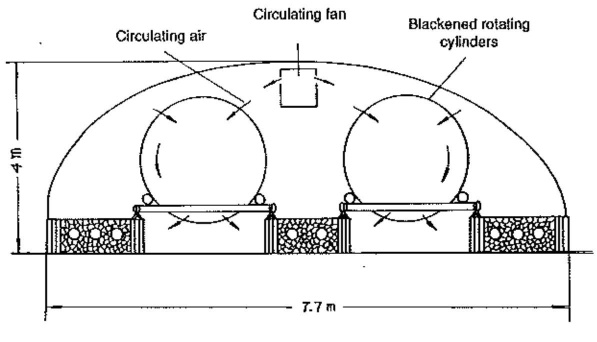

Fig. 6. Sketch of arch dryer with drums.

Figure 7 shows a side and front view of a tent solar dryer. In Indonesia a simple tent solar dryer has been built for drying salted fish, tempe, manioc and sliced potatoes. The temperature in the tent dryer rises to 40-55°C, when the ambient temperature is 30-32°C. The cost is very low, because it is made of plastic sheet, bamboo, nails and iron wire. In the Philippines, people also use tent dryers to dry mangoes, jackfruits, papayas and bananas.

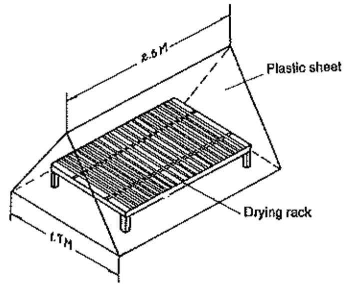

Fig. 7. Side and front view of a tent solar dryer.

NEW DEVELOPMENTS

Over the last decade new technology has been used to improve greenhouse solar dryers. The emphasis has been on the design of new types, heat storage, dewatering the moisture of the drying air and using heat pipes and heat pumps.

New Designs

In the United States, an experimental solar dryer with a reflector has been constructed. The schematic representation is shown in Fig. 8. This device combines the greenhouse dryer with the concentration dryer. In this way the drying product can get concentrated sunlight underneath. The module has a 1.1 m^2 drying surface and a parabolic trough reflector area of 3.3 m^2. The seven-ply laminated wooden parabola is framed with 5.1 cm x 5.1 cm wooden supports. Polyethylene sheet encloses the dryer except for two slots (5.1 cm x 1.2 cm), which serve as an air inlet and an exhaust. The trays are made of perforated aluminium sheet. Experiments show that the drying rate for mango slices is about 0.5 kg water per square metre per hour in the drying season. The flavour quality of the resulting dried mango is very acceptable.

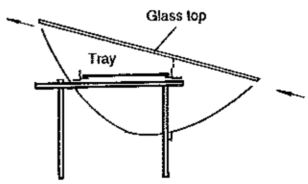

Fig. 8. A schematic diagram of a solar dryer with a reflector.

In USA, there is another type of solar dryer with a reflector (Fig. 9). This dryer can accelerate the fruit drying rate by exposing the drying trays to a greater amount of solar radiation. The dryer consists of a half-cylinder with trays covering one-half of the opening. During drying, all the direct solar radiation entering the trough is reflected up onto the bottom of the trays. In contrast, a trough without trays would reflect back most of the radiation energy outside the trough. The trough is made of plywood. It is 1.87 m long, 1.27 m wide and 0.63 m high, and it can accommodate three trays (60 cm x 60 cm). The trays are made of metal, since spot temperatures can be very high. This dryer is used to dry halved and sulphurated apricots. Experiments have shown

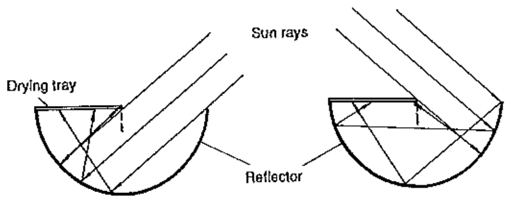

Fig. 9. Section view of trough solar dryer.

that drying apricots to 24% moisture content by conventional means requires about 50 hrs, compared to 31 hrs for this device, thereby reducing the drying time by 40%. During peach drying, the comparison is 80 hrs (solar dryer) and 150 hrs (conventional method) to achieve 24% moisture content, providing a reduction in drying time of 45%.

The University of Hawaii has designed an experimental solar dryer with reflectors (Fig. 10) [9]. The dryer consists of a drying box and four reflectors. The drying cage uses aluminium screens for good sanitation and air ventilation. The four reflectors are detachable and are made of plywood and wood with 0.64 cm thick plastic mirrors used as reflectors. The drying cage sits on a perforated wooden base, and has three internal screen shelves. Experiments have shown that reflectors can raise the temperature in the drying cage by 2-8°C. Used to dry taro slices at a loading density of 7.3 kg per square metre, the dryer is very efficient, compared with an air collector dryer. This dryer has some problems in use, since the construction is complicated, and the cage does not shelter the drying products from rain and dust.

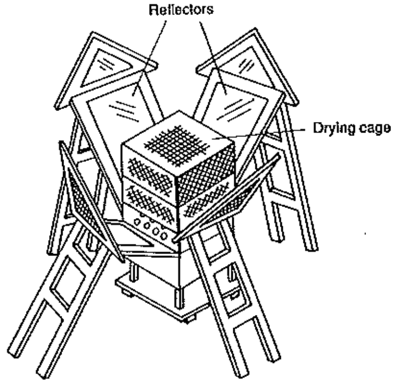

Fig. 10. A cage solar dryer with reflectors.

In China there is a simple plastic solar dryer, which is partially below ground level (Fig. 11). The mouth diameter of the pit is 5 m, and the depth is about 1.3 m. On the floor, there is a black plastic sheet, and over the pit there is a transparent plastic sheet supported by a bamboo frame. On the sides are two ventilation vents. The dryer is used to dry fruits and to heat air for tobacco drying in Peru, a similar plastic solar dryer is also used for drying potatoes.

Figure 12 shows a greenhouse dryer with an insulation board faced with aluminium foil [10]. During day-time, the aluminium foil reflects sunlight onto the ground in the dryer, and at night the

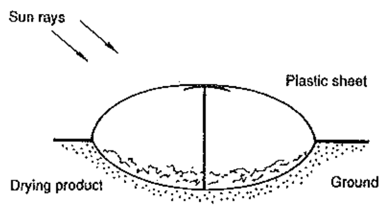

Fig. 11. Section of simple solar dryer.

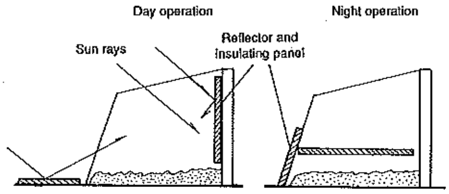

Fig. 12. A dryer with an insulation board.

board, when closed, acts as an insulation layer.

There are a variety of new types of greenhouse solar dryers. Some are hybrid, using fans to accelerate the ventilation of the air. For natural convection dryers values of 10-15% are typical, whereas for forced convection dryers a higher value of 20-30% can be expected. Some use auxiliary plastic air heaters to increase the heat for drying. Others are combined with storage bins.

Heat Storage Systems

Generally speaking, the temperature for drying agricultural products is comparatively low. However at noon the temperature in some of the solar dryers is much higher than needed, so considerable research work on heat storage systems has been done in recent years. Researchers use not only conventional materials, such as rocks and water (for sensible heat), but also phase change materials and some organic compounds (for latent heat).

Using rock and water for heat-storage has been discussed in many papers. The terms, such as rock bins, pebble beds, and water tanks are familiar. Sensible heat storage is simple. In the case of rock storage only requirement is a container of rocks through which air is passed. The heat capacity of the rocks is considerably less than that of water but the density is greater and a cubic foot of solid rock stores about 9.0 Kcal per °C (20 BTU per °F) whereas a cubic foot of water stores 28.3 Kcal per °C (62.5 BTU per °F). Work is continuing on the use of phase-change materials and organic compounds, such as salt hydrates, stearamide, calcium chloride hydrates and other materials. A phase-change material should have a high latent heat effect and should be reversible over a very large number of cycles without serious degradation. Superheating, erosion, toxicity and cost should also be considered. As this paper is of limited scope, these details can not be discussed here.

Using the floor to store heat in greenhouses is currently being investigated in Canada, Japan, Australia and some European countries.

Figure 13 shows a scheme for using the floor to store heat. An array of pipes each of diameter 10 cm, is buried 0.5-0.7 m below the soil surface. At the end of the pipes there are two ditches. One of the ditches is covered and has two vents for fans. When the temperature in the greenhouse is higher than needed, the fan will force hot air into the underground pipes. At night, when the temperature in the greenhouse is too low, the fans will force air through the pipes, transmitting the heat stored in the floor to the air. Floor storage for solar dryers has not been studied in depth.

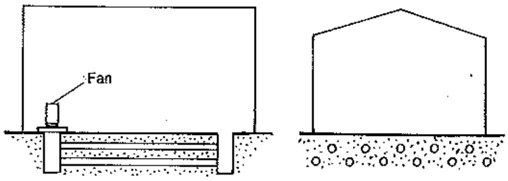

Fig. 13. Using floor to store heat.

New Storage System Ideas

Zeolite has been investigated as a storage material. It is solid with many holes. When hot air passes through it, the zeolite will raise its temperature by absorbing the moisture of the hot air. At night, when heat is needed, wet air is passed through zeolite, the moisture is absorbed and gives up the stored heat. Experiments show that zeolite is a promising heat storage material.

There have been many heat storage experiments, but few have been used practically, and more work will have to be done before the ideas are in general use.

Dewatering the Moisture of Drying Air

Dewatering the moisture of the air in a solar dryer is an attractive research subject. During drying, humid hot air escapes a solar dryer through the chimney or vents, causing heat loss. To recover the lost heat, various designs of heat exchanger have been suggested that allow the heat of the hot air to be transferred to the inlet fresh cold air. In the USA, a heat exchanger or air preheater using exhaust humid hot air at 49°C can raise the temperature of fresh air from 21°C to 45°C, with a heat recovery effectiveness of about 68%. The most important factor is the design of the air heat exchanger.

Use of a desiccant can also remove the moisture of the drying air in solar dryers. Usually it is zeolite, silica gel, active carbon, quick lime or calcium chloride. The process is as follows: During dewatering, the humid air passes through the desiccant which has previously been dried to a state in which its equilibrium relative humidity is below that of the air. In this case the desiccant will absorb the moisture of the humid air. When the desiccant contains too much moisture, dry hot air from a solar air heater can be used to dry it, removing the moisture.

CONCLUSIONS

Passive greenhouse solar dryers play an important role in all solar drying, particularly in the developing countries, for drying agricultural products. From this survey, we can draw the following conclusions:

- **They are simple to construct and easy to operate:** The construction of most passive greenhouse dryers is simple. Some of them can be built by the farmer himself with locally available materials. The processing operation is also simple, and there is no danger of burning.
- **Different designs suit different products:** There are a variety of passive greenhouse solar dryers, different types being required for different products. Before deciding to make a solar dryer, it is necessary to evaluate the requirement, the quality of the drying products, the market and the cost.
- **Existing dryers can be improved:** Choosing of appropriate technology to improve the existing greenhouse solar dryers is a vital research subject. It is accepted that in some instances it is important to combine a greenhouse solar dryer with fans and auxiliary air heaters. Hybrid solar dryer seems to be more useful. Developing countries should use appropriate materials, such as bamboo, and new low cost materials such as plastic sheet.
- **They can be designed for multi-purpose use:** As agricultural product drying is seasonal, a greenhouse solar dryer should be designed for multi-purpose use. Some solar dryers can be used for nurseries or mushroom beds, others can be used as animal shelters or storehouses. In this way the investment can be recovered within a short time.
- **New technologies should be used to improve performance:** The greenhouse dryer is not yet commercially available, since it is in its infancy as an emergent technology. To improve its performance, research work should be carried out using new technologies, such as new materials, heat storage systems, dewatering of the moist drying air.

REFERENCES

1. Brenndorfer, B. et al. (1985), *Solar Dryer – Their Role in Post-Harvest Processing*, Commonwealth Science Council, London.
2. Jolly, P.G. et al. (1987), Review of Solar Drying, *Proceedings of the Annual Conference of the ANZSES*, 1987.
3. Boonthumjinda, S. et al. (1983), Field Tests of Solar Rice Drying in Thailand, *Proceedings of Solar World Congress*, 1983.
4. Sun Xiaoren (1986), Solar Dryer for Chinese Dates, *Proceedings of Rural Energy Symposium*, Beijing, 1986.
5. Anon (1965), *How to Make a Solar Cabinet Dryer for Agriculture Produce, Do-it-yourself Leaflet L6*, Brace Research Institute, Canada.
6. Clark, C.S. (1982), A Solar Food Dryer for Bangladesh, *Appropriate Technology*, Vol.8, No.4.
7. Sandhu, B.S. et al. (1979), Design Development and Performance of Multi-rack Natural Convection Dryer, *Proceedings of ISES*, 1979.
8. Ozusik, M.N. et al. (1980), Solar Grain Drying, *Solar Energy*, Vol.24, pp.397-401.
9. Moy, J.H. et al. (1980), Solar Drying of Taro Roots, *Transaction of the ASAE*.
10. Shurcliff, W.A. (1979), *New Inventions in Low Cost Solar Heating*, Brick Home Publishing Company, USA.