33) SUN AND SOLAR DRYING, TECHNIQUES AND EQUIPMENT

I. SUN DRYING

Food drying is a very simple, ancient skill. It is one of the most accessible and hence the most widespread processing technology. Sun drying of fruits and vegetables is still practised largely unchanged from ancient times. Traditional sun drying takes place by storing the product under direct sunlight.

Sun drying is only possible in areas where, in an average year, the weather allows foods to be dried immediately after harvest. The main advantages of sun drying are low capital and operating costs and the fact that little expertise is required. The main disadvantages of this method are as follows: contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew that wets the product, encourages mould growth and may result in a relatively high final moisture content; low and variable quality of products due to over- or under-drying; large areas of land needed for the shallow layers of food; laborious since the crop must be turned, moved if it rains; direct exposure to sunlight reduces the quality (colour and vitamin content) of some fruits and vegetables. Moreover, since sun drying depends on uncontrolled factors, production of uniform and standard products is not expected.

The quality of sun dried foods can be improved by reducing the size of pieces to achieve faster drying and by drying on raised platforms, covered with cloth or netting to protect against insects and animals.

II. SOLAR DRYING

Due to the current trends towards higher cost of fossil fuels and uncertainty regarding future cost and availability, use of solar energy in food processing will probably increase and become more economically feasible in the near future.

Solar dryers have some advantages over sun drying when correctly designed. They give faster drying rates by heating the air to 10-30?C above ambient, which causes the air to move faster through the dryer, reduces its humidity and deters insects. The faster drying reduces the risk of spoilage, improves quality of the product and gives a higher throughput, so reducing the drying area that is needed. However care is needed when drying fruits to prevent too rapid drying, which will prevent complete drying and would result in case hardening and subsequent mould growth. Solar dryers also protect foods form dust, insects, birds and animals. They can be constructed from locally available materials at a relatively low capital cost and there are no fuel costs. Thus, they can be useful in areas where fuel or electricity are expensive, land for sun drying is in short supply or expensive, sunshine is plentiful but the air humidity is high. Moreover, they may be useful as a means of heating air for artificial dryers to reduce fuel costs (1)

Solar food drying can be used in most areas but how quickly the food dries is affected by many variables, especially the amount of sunlight and relative humidity. Typical drying times in solar dryers range from 1 to 3 days depending on sun, air movement, humidity and the type of food to be dried.

The principle that lies behind the design of solar dryers is as follows: in drying relative and absolute humidity are of great importance. Air can take up moisture, but only up to a limit. This limit is the absolute (maximum) humidity, and it is temperature dependent. When air passes over a moist food it will take up moisture until it is virtually fully saturated, that is until absolute humidity has been reached. But, the capacity of the air for taking up this moisture is dependent on its temperature. The higher the temperature, the higher the absolute humidity, and the larger the uptake of moisture. If air is warmed, the amount of moisture in it remains the same, but the relative humidity falls; and the air is therefore enabled to take up more moisture from it's surrounding.

To produce a high-quality product economically, it must be dried fast, but without using excessive heat, which could cause product degradation. Drying time can be shortened by two main procedures: one is to raise the product temperature so that the moisture can be readily vaporized, while at the same time the humid air is constantly being removed. The second is to treat the product to be dried so that the moisture barriers, such as dense hydrophobic skin layers or long water migration paths, will be minimized (2).

II. 1. Types of Solar Dryers

There are mainly three types of solar dryers (3):

1. The absorption or hot box type dryers in which the product is directly heated by sun,
2. The indirect or convection dryers in which the product is exposed to warm air which is heated by means of a solar absorber, or heat exchanger,
3. Dryers combining the principles of the above two, where the product is exposed to the sun and a stream of pre-heated air simultaneously.

II. 1. 1. Direct Absorption Dryers

Direct drying consists of using incident radiation only, or incident radiation plus reflected radiation. Most solar drying techniques that use only direct solar energy also use some means to reflect additional radiation onto the product to further increase its temperature.

An example of direct absorption dryer is the hot box dryer as shown in Figure 1 (3). The aim of this type of a dryer is mainly to improve product quality by reducing contamination by dust, insect infestation, and animal or human interference. It consists of a hot box with a transparent top and blackened interior surfaces. Ventilation holes in the base and upper parts of slide walls maintained a natural air circulation.

Figure 1: Direct absorption dryers. (A) glass cover, (B) ventilation holes.
Arrows indicate airflow.

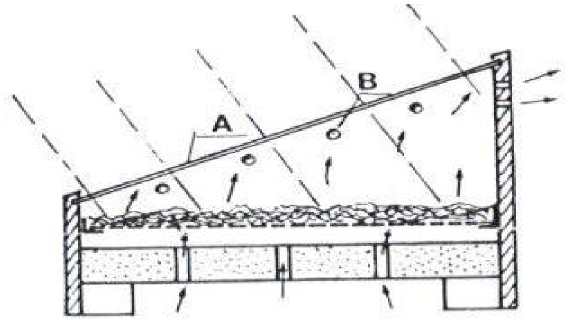
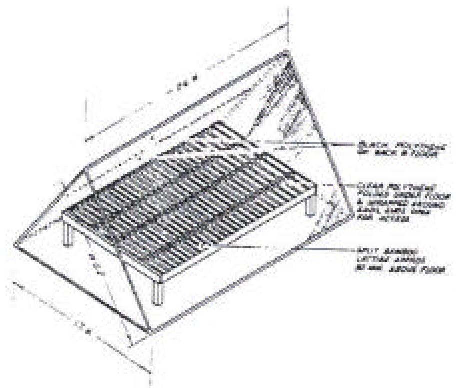


Figure 1
Direct absorption dryer. A: Glass cover B: Ventilation holes. Arrows indicate ai flow.



II. 1. 2. Dryers With Solar Air Heaters

In figure 2, a greenhouse type drying chamber is shown (4). The main idea behind this type of a dryer is to obtain a low cost multi-product system. The leads to choose a drying chamber able to accommodate different kinds of trays and act in it self as a solar collector.

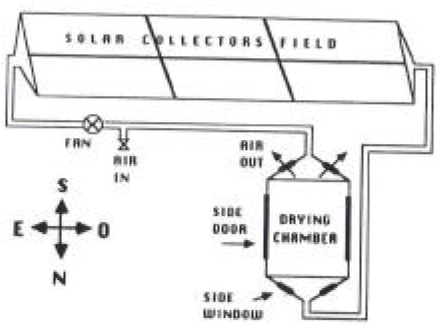


Figure 2. Greenhouse Type Solar Drying System.

The drying chamber has the shape of a parallelpiped with its longitudinal axes in the North-South direction. A wooden frame supports a transparent polycarbonate hollow plate 4.5 mm thick. The wooden skeleton and polycarbonate plates are screwed together allowing the whole chamber to be disassembled easily. The construction is modular to permit variations of the drying chamber capacity. Trays have a shape that they can be piled easily without crushing the fruits and allow air circulation between them following the main axis. Four small windows located at the far ends of the chamber enable introduction of measuring devices and also control the air rene wal in the system. Eight fans placed inside the chamber produce and internal recycling, and cause the air flux to be uniform. The drying system has six solar collectors made of blackened iron plate, protected by a glass cover, which also helps to decrease heat losses (4).

The solar tunnel dryer (Fig.3) consists of a plastic sheet-covered flat plate solar col1ector, a drying tunnel and three smal1 axial flow fans (5). To simplify construction and reduce costs, the solar col1ector is connected directly to the drying tunnel without any additional air ducts. Plastic foam sandwiched between two paral1el metal sheets is used as a back insulator for both the col1ector and drying tunnel. This insulator also functions as the structure of the dryer. The top surface of the insulator in the col1ector is painted black to absorb solar radiation. The col1ector is covered with a transparent u. v .-stabilized PE plastic sheet that is fixed to the col1ector frame using reinforced plastic clamps. For the drying tunnel, a wire mesh is placed on top of the insulators. A sheet of plastic net, on which the product to be dried are spread, is placed on top of the wire mesh. This arrangement allows drying air to flow around the whole surface of the product being dried. The drying tunnel is also covered with a u. v .-stabilized air bubble plastic sheet. One side of this sheet is fixed to the tunnel frame and the other side is fixed to a metal tube allowing the sheet to be rolled up and down for loading and unloading the dryer. Fastening plastic profiles, as shown in Fig. 4, are used to fix the sheet to the tube and also to the drying tunnel frame. This fixing method is designed to facilitate the replacement of the sheets. In general, the transparent sheet can be used for 1-2 yr and the air bubble sheet lasts for 3-5 years. Three small fans powered by a 53 W solar cell module are installed in the back of the collector to suck ambient air into the collector as shown in Fig. 5. The fans are intentionally installed below the solar module to constantly reduce its temperature, thus maintaining its efficiency. Both the collector and the drying tunnel are installed on concrete block substructures. All parts of the dryer, including the back insulator and metal frames, are designed using a modular concept, which facilitates the transport and installation of the dryer. This solar tunnel dryer uses solar energy both in the thermal form for the drying process and the electrical form for driving the fans, by means of the solar collector and solar module respectively. Therefore, the dryer could be used in rural areas where there is no supply of electricity.

A rock-bed dryer is shown in Fig. 6. In this dryer, air, drawn by natural convection through an air inlet (A), circulates the heat collected by the primary solar energy collector (B), throughout the drying chamber (C) which is packed with limestone rocks of relatively uniform diameter. The heat would then stratify across the rock bed but, since rocks are poor thermal conductors, temperature differences would slowly disappear when air is not moving through the rock bed. Thus samples positioned above the rock-bed can continue drying during the night. This type of a solar dyer requires very little maintenance (6).

II. 1. 3. Combined Direct and Indirect Dryers

Many types of drying systems utilize both direct and indirect solar radiation. In these types of systems, radiant energy from the sun falls directly onto the product being dried; however, in addition, a preheater also is used to raise the air temperature, which in turn, accelerates the drying rate. Acceleration of drying rate can occur in two ways: hot air can transfer some of its heat to the product being dried, thus raising its vapour pressure causing a faster moisture loss; or as temperature of air mass increases, the water-holding capacity also increases (2, 3).

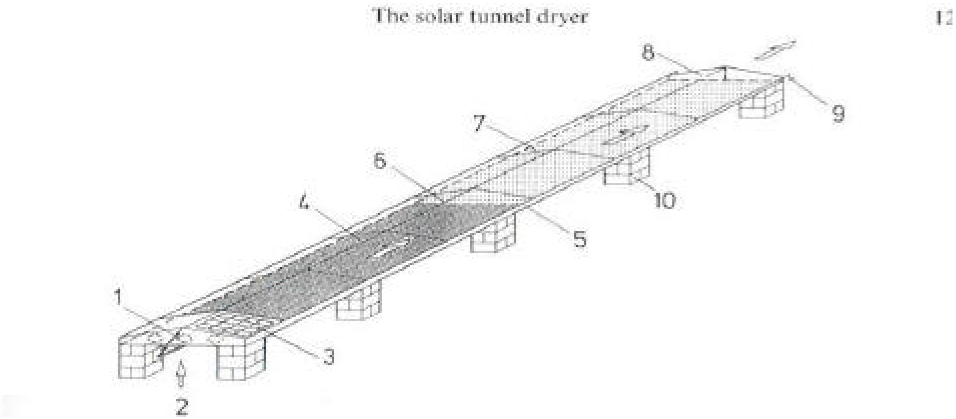


Figure 3. Solar tunnel dryer: 1.Fan, 2. Inlet air, 3.solar cell module, 4. Solar collector, 5. Metal frame, 6. Outlet of the collector, 7. Drying tunnel, 8. Outlet of drying, 9. Rolling bar, 10. Concrete block substructure

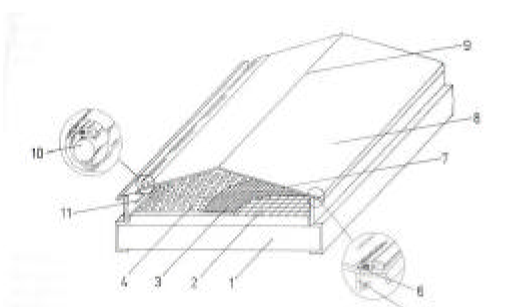


Figure 4. Drying tunnel: 1.Back insulator, 2. Wire mesh, 3. Plastic net, 4. Product to be dried, 5. Metal frame, 6. Fastening plastic profile, 7. Metal strip, 8. Air buble plastic sheet, 9. String for supporting sheet, 10. Metal tube for rolling the sheet, 11. Rolling bar

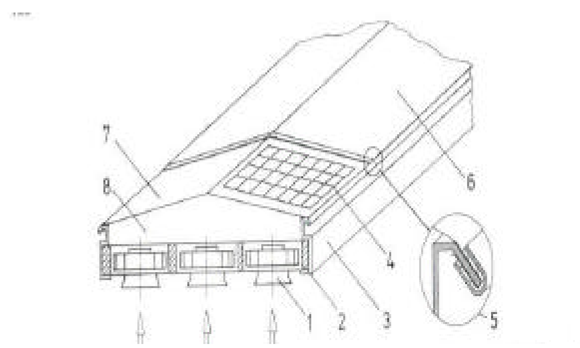


Figure 5. Solar collector: 1. Fan, 2. Back insulator, 3. Metal frame, 4. Solar cell module, 5. Reinforced plastic clamp, 6. Transparent plastic sheet, 7.-8. Metal sheet

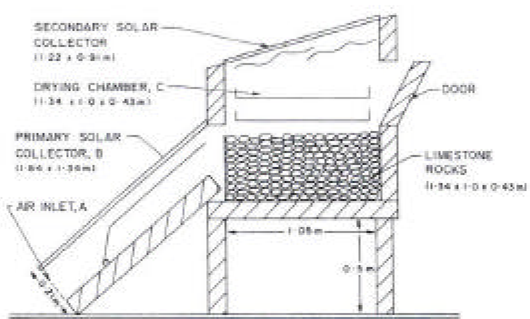


Fig 1. Rock-bed solar dryer.

Figure 6. Rock-bed solar dryer.

II. 2. Solar Drying of Fruits & Vegetables

II. 2. 1. Tomatoes

Due to the increasing demand to dried tomatoes from the industry, especially from the soup manufacturers, interest in producing high quality dried tomatoes has been increasing. Therefore, it is important to establish a drying method, which yields products with higher sensory and sanitary quality in a shorter drying time compared to the conventional sun-drying method. Both 2% $Na_2S_2O_5$ and 2% citric acid pretreatments can be used to protect the bright, red colour of tomatoes. However, citric acid did not prevent the growth of moulds and yeasts effectively. Therefore, dipping into sodium metabisulfite solution for 3 minute is the best type of pretreatment. Tomatoes can be dried at 55°C in solar tunnel dryer without a darkening in colour. At this temperature the drying takes 4-5 days to a final moisture content of 11 % (7).

II. 2. 2. Red Pepper

Red peppers are deseeded, cut into small pieces, and washed before loading into the tunnel solar dryer. Pretreatment with 2% $Na_2S_2O_5$ for 1 second gives the best colour. Moreover, the drying temperature and piece size of red peppers affects the final product quality. Temperatures higher than 60°C results in dark brown colour formation in red peppers. Red peppers that are cut into bigger pieces needs a longer time period to dry and therefore the colour of the final product is darker. Drying at low temperatures (45-50°C) for about 1 day gives good results. To increase the capacity of the solar dryer, a double layer system can be constructed, but with this system, drying needs a more careful control. Final moisture content of dried red peppers which are pretreated with 2 $Na_2S_2O_5$ for 1 second is 3.5%. The yield is 9% for both pretreated and naturally dried peppers (7).

II. 2. 3. Green Pepper

Green peppers are used especially in the soup manufacturing. Therefore, establishing an efficient and economic method for peppers is important for the food industry. Green peppers are washed, deseeded and cut into small pieces before loading into the dryer. Green peppers are very sensitive to high temperatures and light. Therefore, green peppers should be dried under dark and at 45-50°C to preserve the natural green colour. 2% $Na_2S_2O_5$ dipping for 1 sec can be applied to obtain a microbiologically safe product. Drying at 45-50°C under dark conditions takes about 1 day. Green peppers dried under these conditions have a final moisture content of 6%, and a yield of 10% (7).

II. 2. 4. Onion

A large part of the dehydrated onion production is used as seasoning in production of catsup, chilli sauce and meat casseroles, as well as cold cuts, sausages, potato chips, crackers and other snack items. Food service outlets also use dehydrated onions because of its convenience in storage, preparation and use. Before drying, onions are peeled and sliced into desired shapes. Onions can be dried at 45-50°C for 2-3 days to a final moisture content of 15 % in tunnel solar dryers. Sodium metabisulfite dipping can be used to preserve colour. Drying temperatures of onions should not exceed 50°C in order to prevent browning of the product. The yield in onion drying is 8% (7).

II. 2. 5. Carrot

Before loading into the dryer, carrots are peeled, washed, cut into small cubes and treated with 2% sodium metabisulfite solution for 1s and 10s or dried as natural. Carrots can be dried at 50-55°C for 1-1.5 days to a final moisture content of 7.5 %. Naturally dried carrots loss their bright orange colour. The sodium metabisulfite treated ones preserve their colour to the largest extent (7).

II. 2. 6. Prunes

It is known that certain treatments used to modify the waxy cuticle of the surface of various fruits (prunes, grapes, cherries, etc.) accelerate the drying as a result of an increase in the skin permeability. Dipping in olive oil emulsions is a traditional practice in direct solar drying of pieces and it is recorded that this increases the drying rate of grapes approximately 30%. Different olive oil concentrations combined with sodium or potassium carbonate or ethyl esters of fatty acids are used for this purpose. Researches have found that the most effective compounds are the ethyl esters of fatty acids in the C_{10}-C_{18} range with ethyl oblate being the easiest to handle. Prunes can be dried at 55-60°C in solar tunnel driers. At this temperature, prunes pretreated with 2% ethyl oleate or 2% olive oil+4% potassium carbonate dried in 3-4 days (7).

II. 2. 7. Peach

Peaches are washed, destoned and sliced 1-2 cm thick. The thickness of the slices is very important since very thin slices causes hardening and brownish colour in the final product. Different concentrations of $Na_2S_2O_5$ and citric acid can be used as pretreatment agent: 2% citric acid for 30s, 1 $Na_2S_2O_5$ for 1 s, and 1 % citric acid + 0.5% $Na_2S_2O_5$ for 1 s. Peaches which are consumed directly or used in recipes can be dried at 45-50°C in 2 days. The yield of the final product is 11 % and final moisture content is about 8.5% (7).

II. 2. 8. Okra

Okra is one of the most popular vegetables consumed in tropical and subtropical countries, because of its adaptability and resistance to hot and humid weather. Before loading into solar dryer, okra is washed and its head is removed. One of the following treatments can be applied to okra prior to solar drying: dipping in 0.2% $Na_2S_2O_5$ for 20 min; 0.1% Na_2S0_3 for 30min; 0.3% $Na_2S_2O_5$ 10 min; 2% $Na_2S_2O_5$ for 1s, and 3 minutes of blanching followed by dipping in 0.2% Na2S03 for 15 min, and finally blanching and dipping in 0.2% Na2S03 for 15 min. On the basis of colour, flavour and microbiology of the final product, it was observed that high quality dried okra was obtained using 2% $Na_2S_2O_5$ dipping as a pretreatment and drying of okra at 50-55°C in the solar dryer under dark conditions. Drying time was about 1day. Blanching of okra before drying needs ice-bath dipping. Therefore it is not considered as a practical method (7).

II. 2. 9. Apple

Golden apples are cleaned, cored and sliced to 3-5 mm thick. To prevent browning, the apples can be immersed for 1s in 2% citric acid or 2% $Na_2S_2O_5$ solutions immediately after slicing.

The apples dried under light conditions becomes a little brown but the ones that are dried without exposure to light are kept their natural, light colour. The choice of drying conditions depends on the consumer's demand. Dried apples have a water activity of 0.38 and a yield of 15% (7).

REFERENCES

1. Fellows, P. Guidelines For Small-Scale Fruit and Vegetable Processors, FAO Agricultural Services Bulletin 127, FAO of the United Nations, Rome, 1997.
2. Boiln, H. R., and Salunkhe, D. K. Food Dehydration by Solar Energy, CRC Critical Reviews in Food Science and Nutrition, April 1982, pp:327-354.
3. Szulmayer, W., From Sun-Drying to Solar Dehydration I and II, Food Technology in Australia, September, pp: 440-501, 1971.
4. Rossello, C., Berna, A., and Mulet, A., Solar Drying of Fruits in a Mediterranean Climate, Drying Technology, 8 (2), pp: 305-321, 1990.
5. Schirmer, P., Janjai, S., Esper, A., Smitabhindu, R., and Mühlbauer, W., Experimental Investigation of the Performance of the Solar Tunnel Dryer for Drying Bananas, Renewable Energy, Vol. 7, No. 2, pp: 119-129, 1996.
6. Narinesingh, D., and Mohammed-Maraj, R., Solar Drying Characteristics of Papaya (Carica papaya) Latex, Journal of the Science of Food and Agriculture, 46, pp: 175-186, 1988.
7. Kaptan, H., and Seylam, A., Solar Drying of Selected Fruits and Vegetables, Unpublished, TUBITAK-MRC, FSTRI, 1996.