A0005 *Solar Distillation and Drying*

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Glossary

G0005 **absorptivity** A property of a surface, defined as the fraction of incident energy absorbed on the surface.
G0010 **convection** A mode of heat transfer in which heat is transferred due to the motion of the fluid.
G0015 **dessicant** A material that absorbs moisture from air.
G0020 **dew point** The temperature at which water vapor in air starts to condense when cooled.
G0025 **drying capacity** The quantity of products that can be dried in a single batch of loading.
G0030 **drying potential** The ability of air to evaporate water from the material to be dried, which depends on the temperature and relative humidity of the air.
G0035 **drying ratio** The ratio of the weight of wet products entering the dryer to the weight of the products leaving the dryer.
G0040 **humidity ratio** The ratio of the mass of water vapor in the air to the mass of the dry air.
G0045 **liner** Any natural black or painted material that can withstand the operating temperature and saline water.
G0050 **natural convection** The motion of the fluid due to buoyancy forces, which arise from density differences, caused by temperature variations in the fluid.
G0055 **regeneration** The process of removal of water from the desiccant.
G0060 **relative humidity** The ratio of the mass of water vapor in a given volume of air to the maximum amount of vapor that the same volume of air can hold at the same temperature and pressure.
saturation The condition at which a fluid holding another substance cannot hold any additional amount at the given conditions. G0065
scale The deposition of minerals on any solid surface. G0070
solubility limit The maximum amount of solid that can be dissolved in a liquid at a specified temperature. G0075
sublimation The phase change of a material directly from solid to gas without passing through a liquid phase. G0080
vapor pressure The actual pressure exerted by vapor. G0085

Solar distillation is the process in which solar heat is used to purify water from an impure water source by evaporation and condensation. When solar distillation is used to purify water from saline water, the process is also called solar desalination. Desalination converts saline water with high salt content, about 3.5% by weight in seawater and about 0.6% in brackish water, into fresh water suitable for drinking and other purposes. Solar energy can be used for desalination, either as thermal energy through the use of solar thermal collectors or solar ponds, or as electricity. mainly through the use of photovoltaic cells. P0005

1. SOLAR DISTILLATION BACKGROUND S0005

Solar distillation has been practiced for a long time. The first large-scale solar distillation plant was constructed in 1872 at Las Salinas, Chile, and consisted of solar stills of about 4700 m^2 total area, producing about 23,000 l/day. Solar distillation gained more attention after World War I, when many devices were developed. Solar distillation is suitable for remote, arid, and semiarid areas, where drinking water shortage is a major problem and solar radiation is high. The drawbacks to using solar energy for distillation are the high initial cost and the intermittent nature of the sun. Due to these limitations, the present capacity of solar desalination systems P0010 worldwide is about 0.01% of the existing large-scale conventional distillation plants. Those plants are small- to medium-capacity installations serving a small number of people and poor communities.

S0010 2. SOLAR DISTILLATION PROCESSES

P0015 Solar energy can be used to supply the required energy for a desalination process either in the form of thermal energy needed for distillation or as electricity that can be used to drive processes requiring electricity. Solar desalination processes can be classified into two categories:

1. *Indirect systems*. These are usually of small or medium capacity and involve two separate subsystems, a solar energy system and a conventional plant for using the collected solar energy to produce fresh water.
2. *Direct systems*. Here the heat collection and distillation processes take place in the same equipment. In such systems, solar energy is used to produce the distillate directly in the solar still. The still acts as a trap for solar radiation (the greenhouse effect). As solar radiation passes through the transparent cover, it gets absorbed by the water and the absorber surface. As a result the water temperature, thus the vapor pressure, increases and becomes greater than that of the cover and the water evaporates. The vapor rises to the cover by natural convection where it is condensed on the inner side of the cover. A gravity feed funnels the condensate into the collection tank.

P0020 Indirect systems involve using a solar system along with a conventional desalination plant and will not be discussed here.

S0015 3. SOLAR STILL

P0025 The most common solar still is a greenhouse type. Greenhouse solar stills are simple to construct and operate with a transparent cover, which may be symmetrical (Fig. 1) or asymmetrical. The main parts of a greenhouse solar still are described next:

Basin. Saline water is kept for distillation in the basin. The basin may be insulated from the bottom to minimize heat loss to the ambient. It is painted black or lined with a black sheet to maximize its absorptivity. The basin may range from 10 to 20 mm deep (shallow basin) to 100 mm or more (deep basin). The basin floor must be inclined slightly, around 1°, to allow for easy drainage of the concentrated brine. The materials needed to construct a still must be resistant to saline water corrosion, and preferably be inexpensive, durable, and available locally. Aluminum, concrete, wood impregnated with a resin, iron painted to resist corrosion, or plastic may be used.

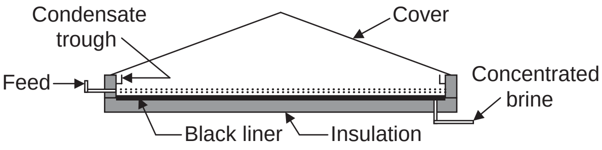


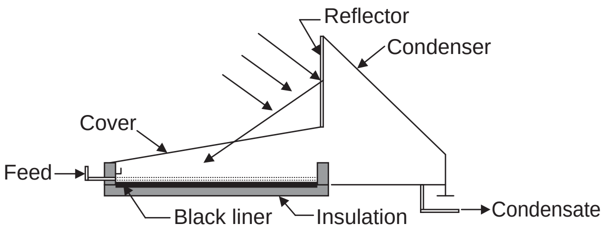
FIGURE 1 Schematic of a symmetrical greenhouse solar still. F0005

Transparent cover. The cover acts as the condenser, so that the vapor condenses on its inside surface and collects at the bottom. It also reduces heat losses from the hot water by keeping the wind away from it. The slope of the cover must be steep enough to allow the water to flow all the way down to the collection troughs, without falling back into the basin. The cover is usually made of glass or plastic, though glass is preferred because of its high transparency, rigidity, and comparatively low cost. One disadvantage of glass is that it breaks on impact. Plastics, on the other hand, are lightweight, inexpensive, less likely to break, and easy to handle. Their main disadvantages are discoloration and deterioration due to ultraviolet (UV) radiation in the sunlight.

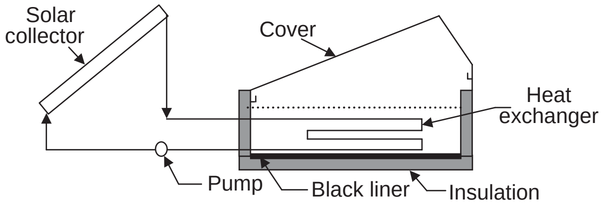
Collection trough. The collection troughs are placed at the lower edges of the cover to collect the distillate. Troughs are pitched along its length so that the distillate flows to the lower end of the still, from where it is collected.

The design of a solar still requires optimization of many factors: brine depth, thermal insulation, cover slope, shape, and material for the still. A well-designed still must also have adequate provision to collect the rainwater that falls on it, so that the surrounding ground is not eroded or flooded. P0030

A variety of basin type solar still designs are used in practice. They differ from each other in the type of materials used, geometry, the method of supporting the transparent cover, and the arrangements for supply and discharge water. The incident solar radiation on the still can be increased by using a reflector (Fig. 2), which focuses it, so that the still receives both the reflected as well as incident P0035



F0010 *FIGURE 2* Schematic of a greenhouse solar still with a reflector.



F0015 *FIGURE 3* Schematic of a greenhouse solar still with a solar collector.

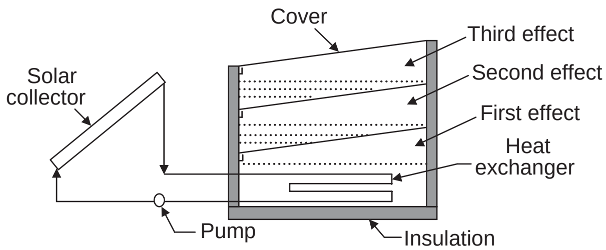


FIGURE 4 Schematic of a multieffect solar still. F0020

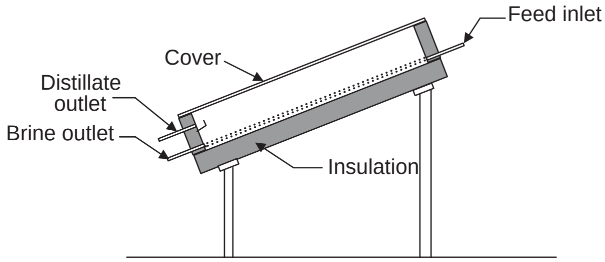


FIGURE 5 Schematic of a tilted solar still. F0025

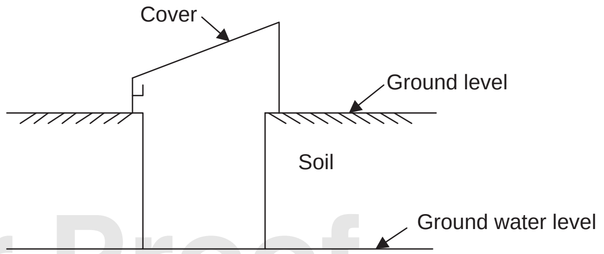


FIGURE 6 Humidity solar still. F0030

radiation. The temperature of the saline water inside the still may be increased by connecting the still to a solar collector (Fig. 3), or the saline water may be preheated in the collector before entering the still. The latent heat of condensation may be partially utilized by means of a multieffect solar still (Fig. 4). As the vapor from one stage condenses at the lower surface of the next stage, it gives up its latent heat at that stage thus evaporating a part of the water there. The condensate flows toward the trough and is collected as the output. Thin film evaporation creates a higher output than pool evaporation. This idea may be used in a tilted solar still, as shown in Fig. 5. The still is tilted to face the sun and the feed water flows from the top inlet toward the bottom. The flow rate needs to be properly controlled to generate the optimum output. Other designs include a tilted wick, which looks like a tilted solar still, an inflated solar still where a plastic sheet is used as the transparent cover, and a still with an internal condenser to enhance the condensation process and to preheat the feed water. Stills based on the humidification-dehumidification principle have also been developed. In a humidification-dehumidification still, saline water is heated in a collection system and pumped to the top of a humidification column. Air is circulated in the opposite direction and becomes humid. The humid air goes to the condenser, where the condensing vapor creates fresh water. In humid areas where there is no fresh or saline water available, fresh water can be obtained from the atmosphere. This can be done by using desiccant materials, which absorb water vapor from the atmosphere. The cooling coil of an air conditioner may be used to produce fresh water, but its temperature must be lower than the dew point of the humid air. As the humid air comes in contact with the coil, the water vapor temperature reduces below the dew point, which condenses as fresh water. For locations with very low humidity and no water resources, fresh water may be obtained from the soil moisture. At a certain depth below the earth surface, the soil remains moist. If that layer of moist soil is heated, vapor will be formed that can be condensed and collected as fresh water. Figure 6 shows a schematic of a possible arrangement.

4. STILL PERFORMANCE S0020

Although the construction and operation of a solar still is simple, the theoretical analysis is complicated P0040 and mostly depends on experimental observations. Basic concepts of a solar still were set forth by R. V. Dunkle in 1961.

P0045 The mass transfer rate

$$(Kg/m^2.s)$$

can be written as

$$\dot{m} = 9.15 * 10^{-7} h_c (p_{wb} - p_{wg}).$$

The heat transfer by evaporation-condensation is

$$q_e = 9.15 * 10^{-7} h_c (p_{wb} - p_{wg}) * h_{fg},$$

where, h_c is the convection coefficient in the still, given by

$$h_c = 0.884 \left[T_b - T_g + \left(\frac{p_{wb} - p_{wg}}{2016 - p_{wb}} \right) T_b \right]^{1/3},$$

where, p_{wb} and p_{wg} are the vapor pressures, in mm Hg, of the solution in the basin at the temperature of the basin (T_b) and of water at the cover temperature (T_g). Temperatures are in degrees Kelvin and h_{fg} is the latent heat of water (*J/kg*).

P0050 Still efficiency, η, is defined as the ratio of the heat transfer, q_e, in the still by evaporation-condensation to the incident solar radiation, *I*, on the still, as given by

$$\eta = \frac{q_e}{I}.$$

Still efficiency is usually low and rarely exceeds 50%, with an average of 30 to 40%. The daily production from a solar still is about 3 to 4 l/m^2.

S0025 5. OPERATION AND MAINTENANCE

P0055 As the water inside the still is almost stagnant, suspended solids in the feed water may settle inside the still. To prevent this, suspended material should be removed from the feed before it enters the still. Growth of algae and other organisms may occur in the still. This can be minimized through the addition of algicides such as copper sulfate to the supply. The presence of scale leads to operating difficulties or loss of efficiency by reducing the heat transfer through the affected surfaces. Therefore, scale prevention is an integral part of the design, operation, and cost of the process. The scale is formed by the dissolved solids in raw water and from corrosion products. Scale usually contains chemical compounds of magnesium oxide, calcium carbonate, and calcium sulfate. The formation of scale can occur where the solubility limits of these compounds are exceeded. When pure water is separated from saline water, the concentration of dissolved solids increases and eventually reaches the saturation limit of one or more salts. Although supersaturated solutions are unstable, solid salts do not necessarily deposit immediately from these solutions. When these solutions come into contact with a solid crystal, the excess dissolved solid in the supersaturated solution precipitates. Crystals of the salt in supersaturated solution and other solids particles can act as centers of crystallization. Therefore, the best way to eliminate the scale formation problem is to flush the still before it reaches saturation.

Stills are designed to operate with water in them, if they are left dry for a period of time they may suffer serious damage. It is also necessary to clean the transparent cover periodically to maintain high transmittance of solar radiation. P0060

6. SOLAR DRYING: DEFINITION AND BACKGROUND S0030

Drying is one of the most important post harvest steps. It enhances the storage life of the crop products, minimizes losses during storage, and saves shipping costs. The drying process is the removal of water from the wet surface of the food. In this process, heat is transferred by convection and radiation to the surface of the produce. This heat raises the temperature and evaporates the moisture from the exterior of the agricultural products, diffusing the interior moisture to the surface and replenishing the evaporated surface moisture. Vapor in the surrounding air is removed by diffusion and movement of air. This process continues until the required drying ratio is reached. So the drying process requires a mechanism for heating the ambient air, a drying unit where moisture removal takes place, and an air handling unit (in some dryers). P0065

The ability of the air to evaporate water from the produce is known as the drying potential. The drying potential depends on both air temperature and relative humidity. Besides the air drying potential, the airflow rate is another major factor determining the drying time. To reduce the drying time, the airflow rate and temperature need to be increased while and air's relative humidity needs to be decreased. P0070

The food type of product to be dried determines the rate of moisture transfer from the interior to the P0075 surface. Nonhygroscopic materials can be dried to zero moisture content; however, hygroscopic materials will always have residually bound moisture. The moisture content present in the agricultural product at equilibrium conditions (when it loses moisture to the environment at the same rate at which it absorbs moisture from the ambient) is known as the equilibrium moisture content or hygroscopic equilibrium. In such a case, increasing the temperature of the drying air will be more effective than increasing the flow rate. It is clear that the process of drying is controlled by the air properties, mainly temperature and relative humidity, and by the agricultural product properties, mainly moisture content.

P0080 The main objective of drying is to supply the required heat in the most effective way to yield the best result with a minimum overall expenditure of energy. For industrial drying hot combustion gases may be allowed to pass directly through the agricultural products, but this method is not preferred because of possible contamination by the unburned fuel. Electrical air heating is preferred, but expensive. In many cases, solar energy may be the most promising source for drying, as some agricultural products, like rice, may be better suited to drying by solar than by fossil fuel systems because case hardening and other damage are less likely at low temperatures.

S0035 7. *DRYING PROCESSES*

P0085 Drying processes range from simple natural sun drying to large-scale industrial drying. Based on the temperature required for drying, the processes may be classified as follows:

1. *Low-temperature drying*. In this slow-drying process (usually performed at temperatures between 15 to 50°C), the air is heated to about 1 to 6°C above the ambient. The main advantages of low-temperature drying include decreased chances of overheating and low capital and running costs, but the process is slow and does not work well for some climates. For low-temperature drying, low-cost solar collectors may be used to heat the air before it enters the dryer.
2. *High-temperature drying*. In this method, air at temperatures above 50°C is used to dry the agricultural products at a fast rate. In such systems, exhaust air from the dryer may be too hot and unsaturated to be wasted, so circulation becomes necessary to improve effectiveness and reduce costs. For this kind of drying, simple solar collectors may not be able to provide the required temperature. Concentrating collectors could be used to achieve the required temperature; however, it may be more economical to use simple solar collectors to preheat the air, and then increase the temperature of the air further using conventional fuel.
3. *Freeze drying*. In such a process, the agricultural product to be dried is first frozen, then placed inside a vacuum chamber connected to a condenser at a low temperature or a desiccant. Heat is applied to the products allowing the water to sublimate, which condenses in the condenser or is absorbed by the desiccant.
4. *Osmovac drying*. This process is normally used for drying fruit juices to make a concentrated powder. It involves two processes, an osmotic process followed by vaporization under vacuum.
5. *Desiccant drying*. In this process, a desiccant is used to remove moisture from the air to increase its drying potential. The desiccant is then regenerated by solar energy. Sometimes a portion of the product itself (especially grain) might be used as the desiccant. If solar energy is used for drying, grain could be overdried during the summer in a desiccant system. At the time of harvest, a part of the overdried grain is removed from the desiccant bin and blended with wet grain to produce a mixture with the average moisture content around the required value. Low-temperature drying may be used to achieve a uniform value for this mixture (i.e., moving moisture from wet to dry agricultural products to reach the required value).

8. *SOLAR DRYING PROCESSES* S0040

Using the sun's energy to dry agricultural products (known as sun drying) is the most widely used form of drying because it is cheap, easy, and convenient. Not long ago, sun drying was the only form of agricultural drying, and it is still the most common agricultural process industry. The easiest and simplest way of sun drying is to spread the products such as fruits, vegetables, cereals, tobacco, and so forth on a suitable surface under the sun and turn them regularly until sufficiently dried so that they can be stored safely. Another important application of sun drying is the evaporation of seawater to produce salt. It is obvious that sun drying would work best in a hot and dry climate with gentle breezes but would be difficult in humid areas. Although sun drying requires little capital or expertise, it has many limitations: irregular and slow drying rate, high final P0090 moisture content especially in humid areas, and variable product quality where some of the products may be overdried and others underdried since there is no control on the drying process. Other problems include contamination with dust and insect infestation, and sudden rain storms, which can soak the products. Also, large areas are required because sunlight is not concentrated. Problems associated with sun drying can be reduced by using mechanical dryers and conventional energy sources like electricity, coal, and fossil fuels. Due to the high cost of conventional energy sources and the associated environmental problems, solar agricultural dryers have gained popularity, particularly in developing countries. Many of these countries are located in areas that receive a good amount of solar radiation.

S0045 9. *SOLAR DRYERS*

P0095 Solar dryers are special structures that enhance the drying power of the sun and protect the agricultural product from dust, dirt, and insects. Figure 7 shows a block diagram of an active solar drying system, consisting of solar air collectors, a drying unit or chamber, and an air handling unit. An active solar drying system can accommodate the use of a backup heat source when there in not enough solar heat available.

P0100 Solar dryers usually employ high airflow rates at low temperatures over long periods of time, whereas fossil fuel dryers usually employ lower airflow rates and higher temperatures for fast drying. Slow drying of fruits and vegetables preserves the flavor and quality of the products much better, which makes solar drying more attractive. Therefore, many commercial solar dryers have already been marketed.

P0105 Drying capacity depends on the size of the dryer and varies with the type of the produce and the amount of moisture to be removed. Placing agricultural products on racks above each other limits the area of exposure of the food surfaces to the drying air, which might result in poor drying. Underloading will result in low efficiency because of not fully using the available capacity. The loading density can be assessed based on the following rules of thumb, which were suggested by M. A. Leon, S. Kumar, and S. C. Bhattacharya in 2002.

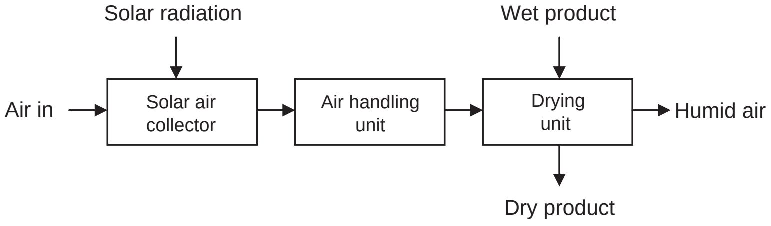
1. Average dryer load is about 4 kg of fresh produce per square meter of tray area.
2. Solar collector area is about 0.75 times total tray area.
3. Airflow rate is about 0.75 cubic meter per minute per meter square tray area.

P0110 There are different types of solar dryers; most of them were developed for specific products or class of products. Selection of a solar dryer represents a compromise between dryer cost, product quality, safety consideration, and installation convenience. Solar dryers may be classified into many categories depending on the mode of heating or operation. According to their operating modes, these can be classified into the following categories:

1. Passive systems: Passive systems use natural forces such as buoyancy and breeze for air flow, therefore, these systems have no external energy input except solar radiation.

a. Direct solar dryers: In such dryers, the agricultural products receive the heat directly from the sun. There are many designs for direct solar dryers, the most important of which are the following:

i. Box solar dryers: These are suitable for arid and semi-arid areas, where the relative humidity is low and the amount of incident solar radiation is high. The low initial cost and easy maintenance are the main advantages of the box dryer. Although box dryers cut the drying period by half in comparison to open sun drying, this period is still very long. Box dryers are usually rectangular, painted black on the inside, and have doors to load and unload the produce. The bottom and sides of the box may be insulated. It has transparent cover on its top. Holes are made at the base and the top of the rear vertical

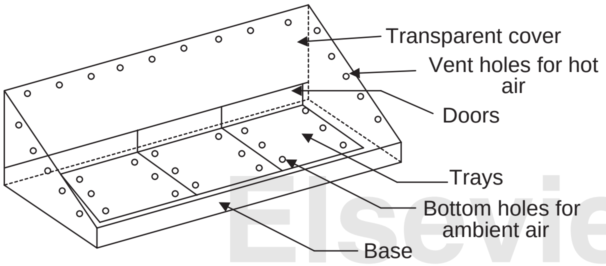


F0035 *FIGURE 7* Block diagram of a solar dryer.

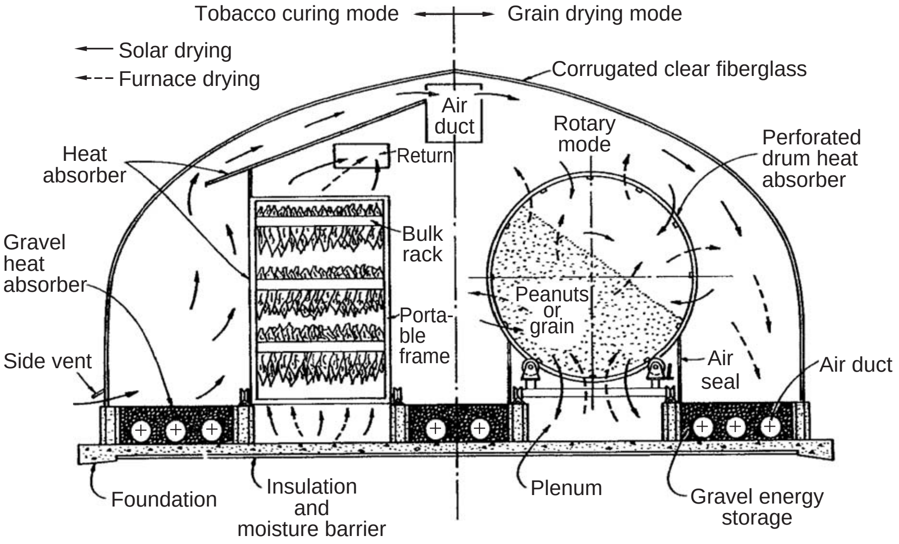
wall (a few centimeters below the cover) to permit movement of air by natural convection. Ambient air enters through the base holes and leaves through the top holes carrying moisture from the products. The agricultural products to be dried are kept in trays, with perforations allowing air flow through them. The trays are placed so that the product receives solar radiation directly. Heat is absorbed directly by the products themselves as well as by the internal surfaces of the drying chamber. The absorbed heat evaporates moisture from the food and induces natural convection, assisting the drying by air circulation. Figure 8 shows a schematic of a possible arrangement known as the solar box dryer. The box's overall dimensions recommend that the length is at least three times the width to minimize the shading effect. Box solar dryers can be made portable or stationary.

ii. Greenhouse solar system: A greenhouse dryer is usually made from a metallic frame covered by transparent plastic or glass with removable inner chambers, which acts as the absorber. Insulating panels may be used over the glazing at night to reduce heat loss, and a means of storing excess daytime heat is often provided. The system as a whole represents a combination of a solar collector and an integrated energy storage device. Figure 9 shows a greenhouse solar system with tobacco curing and grain drying modes (at the left and right, respectively), with an illustration of typical air flow patterns for solar drying and furnace drying. The incident solar radiation gets absorbed on the moveable black absorber. The useful heat is continuously removed by the slow rotation of the absorber and transferred to the agricultural products. Under such conditions, the dryer will most likely be an active one. For nongrain products, the absorber remains stationary. Such systems are usually of medium capacity.

iii. Rack type solar dryers: These dryers are mostly used for drying grapes. The dryer usually consists of 6 to 10 racks, each about 50 to 100 m long, 2.5 m high, and 1.5 m wide, with a north-south orientation lengthwise. Each rack is fitted with galvanized wire netting, spaced at about 25 cm from each other. The outside frame can be made of steel or wood. Products are placed or hung from the wire mesh. The whole structure is normally covered with iron sheets, and side curtains are sometimes used for protection from dust, rain, and excessive sunshine. Racks are usually constructed 9 to 12 m apart to ensure that the agricultural products are exposed to sunlight during the morning and afternoon hours. The racks are preferably placed in an exposed area, clear of any obstruction to permit free air flow.



F0040 *FIGURE 8* Schematic of a box type solar dryer.

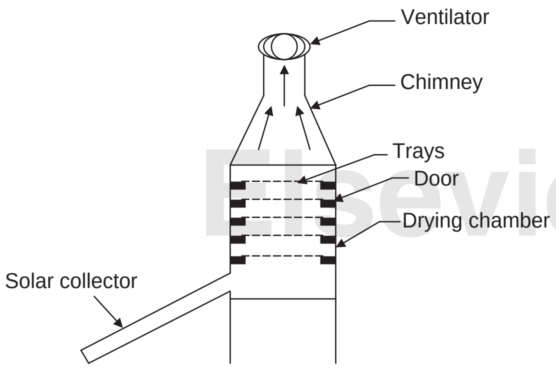


F0045 *FIGURE 9* Greenhouse solar system.

b. Indirect solar dryers: This mode of drying is important especially when the products must be dried under certain specifications of temperature, humidity, and drying rate. In such dryers, the products are placed inside an opaque drying chamber, and solar collectors, usually air type, provide the hot air. Dryers of this type consist of solar air collectors and a drying chamber. The design of such dryers is the same as the conventional fuel type—the only difference is that the heat source is completely or partially solar energy. Some indirect solar dryers are described next:

i. Solar cabinet dryers: The air is heated in the collector and moves upward toward the bed due to buoyancy forces. The products to be dried are laid on the bed, which usually consists of many trays, placed close to the exit section of the collector. As the air moves across the bed, it picks up moisture from the products. Figure 10 shows one possible design of such systems.

ii. Geodesic dome solar fruit dryers: The dome shape (Fig. 11) of these greenhouse dryers makes them perform better than the conventional gable and semicylindrical shapes because they are able to collect more energy from the sun. The dryers are formed from a dome structure covered from the outside by a transparent cover and from the inside by a black plastic absorber. The transparent cover and the black absorber are separated by a suitable distance, about 1 foot. The drying trays are placed inside the inner dome. Air between the transparent cover and the black absorber is heated up by solar radiation and passed through the drying trays before it leaves the dome. The air flow can be by forced convection (Fig. 12A) or by natural convection (Fig. 12B)



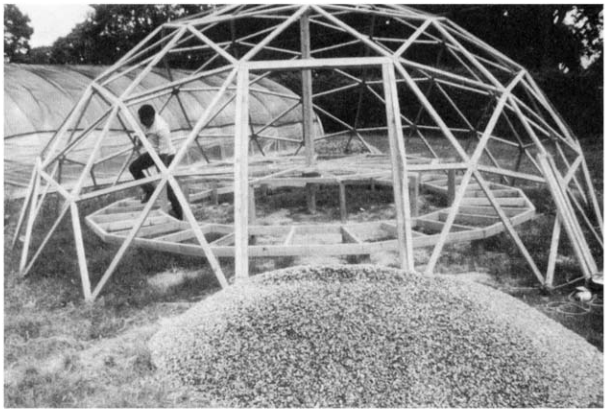
F0050 *FIGURE 10* Schematic of a cabinet type solar dryer.

c. Mixed type dryers: In mixed type of dryers, the products are heated by the hot air from the solar collectors and by direct solar radiation absorbed by them. The sides and the top of the drying chamber can be made of a transparent material, where the products absorb the solar radiation directly. Figure 10 is one possible arrangement showing the front and side walls of drying chamber as transparent.

2. Active systems: An electricity-driven blower or fan is used to circulate the air in active systems. These are further classified as follows:

a. Direct solar dryers: These consist of a drying chamber with a transparent cover and a blower. The solar radiation passing through the transparent cover heats the air. The blower forces the air to pass through the products where it picks up the moisture. Figure 8 shows one possible arrangement with a blower or a fan fixed at one side to circulate the air.

b. Indirect solar dryers: In such dryers, the air heated in the solar collectors is ducted to the drying chamber, where it evaporates and removes the moisture. Some of the most important designs of



F0055 *FIGURE 11* Structure of geodesic dome dryer.

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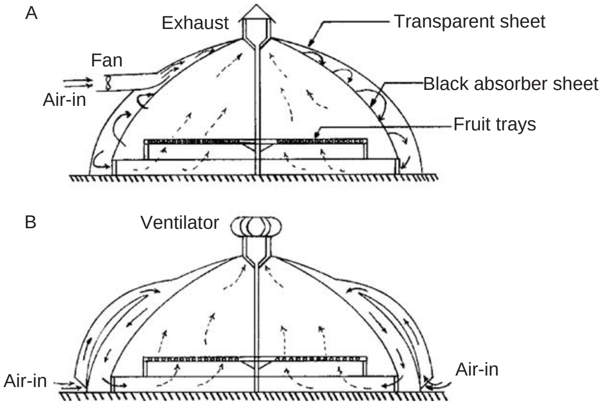
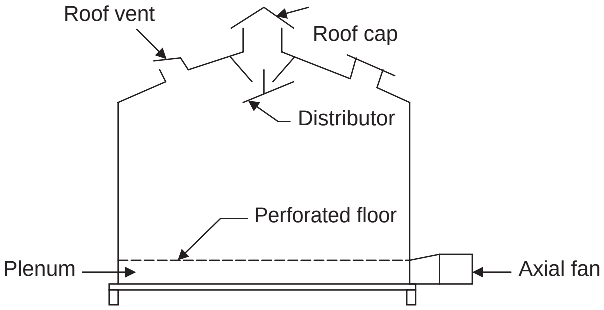
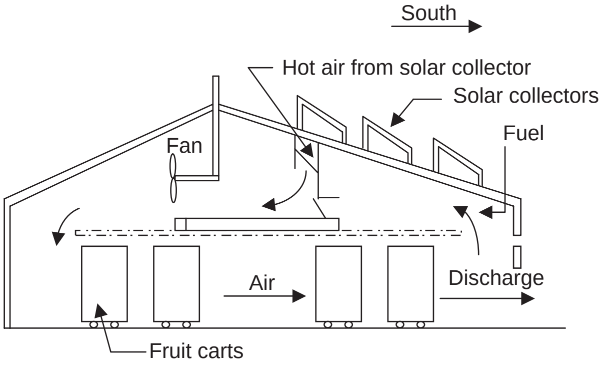


FIGURE 12 Modes of airflow in a geodesic dome dryer. (A) Forced air configuration. (B) Natural air configuration. F0060



F0065 *FIGURE 13* Schematic of a bin dryer.



F0070 *FIGURE 14* Schematic of an industrial dryer.

this type are the following:

i. Bin-type grain dryers: In these dryers, the bin is filled to the top and the hot air from the solar collector is blown from the bottom. Figure 13 shows a schematic diagram of this type.

ii. Shelf-type dryers: The drying chamber consists of many holding trays to increase the capacity of the dryer. The dryer design is similar to that in Fig. 10, but the air is circulated with the help of a blower.

iii. Hybrid or industrial dryers: Such systems use a backup source of conventional energy when solar energy is not sufficient or during off-sun hours. These are usually of a continuous process type and have large capacities. Figure 14 shows a schematic of such dryers.

c. Mixed-type dryers: These are similar to passive dryers, but air is circulated with the help of blowers or fans.

S0050 10. DRYER PERFORMANCE

P0115 The amount of heat utilized in evaporating the water, q_e, can be calculated as

$$q_e = \dot{m}_e h_{fg},$$

where, h_{fg} is the latent heat of evaporation, and $\dot{m}_e$ is the amount of water evaporated in the dryer per unit area perpendicular to the direction of the flow:

$$\text{Dryer overall thermal efficiency, } \eta_d(\%) = \frac{\text{output}}{\text{net input}} * 100 = \frac{q_e}{q_{input}}.$$

If a solar collector of efficiency η_c is used to supply the hot air, the overall efficiency of the system will be

$$\eta_{ovetall} = \eta_d \eta_c.$$

In the case of active solar dryers, the energy consumed by the blower or fan is accounted for in the input. Also in the case of hybrid dryers, the amount of conventional energy consumed is added in the solar input.

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