DRYING OF FOODS

Introduction

There are two main reasons for drying food:

- to prevent (or inhibit) the growth and activity of micro-organisms and hence preserve the food
- to reduce the weight and bulk of food for cheaper transport and storage.

When carried out correctly, the nutritional quality, colour, flavour and texture of re-hydrated dried foods are only slightly less than fresh food. However, if drying is carried out incorrectly there is a greater loss of nutritional and eating qualities and, more seriously, a risk of microbial spoilage and possibly even food poisoning.

This technical brief describes some of the requirements for proper drying and summarises information on the various drying equipment available.

The principles of drying

In the most basic terms, drying is the removal of water from foods. Usually foods are dried using hot air to remove the water. In some instances, such as when gari is being made from cassava, a hot metal pan is used which comes into contact with the food and causes the moisture to evaporate. This technical brief, concentrates on drying using hot air.

For effective drying, the air should be **hot**, **dry** and **moving**. These factors are inter-related and it is important that each factor is correct (for example, cold moving air or hot, wet moving air are both unsatisfactory). The dryness of air is referred to as the humidity - the lower the humidity, the dryer the air. There are two ways of expressing humidity; the most useful is a ratio of the water vapour in air to air which is fully saturated with water. This is known as the relative humidity (RH). Air that is completely dry has a RH of 0% and air that is fully saturated with water vapour has a RH of 100%.

The basics of drying

Drying involves removing water from the food product into the surrounding air.

For effective drying, air should be **hot**, **dry** and **moving**. These factors are inter-related and it is important that each factor is correct:

- air must be dry, so it can absorb the moisture from the fruits and vegetables
- heating the air around the product causes it to dry more quickly
- if the air is not moving across the food, it cannot get rid of the water vapour that it has collected. A fan or air blower is needed to keep the air circulating.

In summary – when food is dried, hot dry air comes into contact with the food. The hot air absorbs water from the food and is moved away from the food. New dry air takes its place and the process continues until the food has lost all its water.

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Air that is not saturated with water (low RH air) has the capacity to pick up and hold more water until it becomes saturated. The principle of drying is that dry air comes into contact with food and absorbs some of the moisture from the food. This air then has to be blown away and be replaced with dry air so that the process of extracting moisture from the food can continue until the food is dry. If wet air (with a high RH) is used, ie in tropical climates where it is fairly humid, it quickly becomes saturated and cannot pick up further water vapour from the food. The drying process in the humid tropics therefore takes longer than in the semi-arid tropics.

The temperature of the air affects the humidity - higher temperatures reduce the humidity and allow the air to carry more water vapour. The relationship between temperature and RH is conveniently shown on a psychrometric chart (see Figure 1).

Note that there are two types of air temperature: the dry bulb and the wet bulb. Both these are used to assess the humidity of the air at a given temperature.

The temperature of the air, measured by a thermometer bulb, is termed the **dry-bulb** temperature. If the thermometer bulb is surrounded by a wet cloth, heat is removed by evaporation of the water from the cloth and the temperature falls (to the **wet bulb** temperature). The difference between the two temperatures is used to find the relative humidity of air on the psychrometric chart see figures 1 and 2).

The dew point is the temperature at which air becomes saturated with moisture (100% RH). Any further cooling from this point results in condensation of the water from the air. This is seen at night when air cools and water vapour forms as dew on the ground. Adiabatic cooling lines are the parallel straight lines sloping across the chart, which show how absolute humidity decreases as the air temperature increases.

Use of a psychrometric chart

A psychrometric chart is a graphical combination of the different characteristics of air that are important in terms of drying. The characteristics included on the chart are the temperature, absolute humidity, relative humidity (%) and air density. The chart has been developed to help with drying calculations and with the design of dryers.
Figure 1 shows a simple version of a psychrometric chart while figure 2 has a more detailed version.

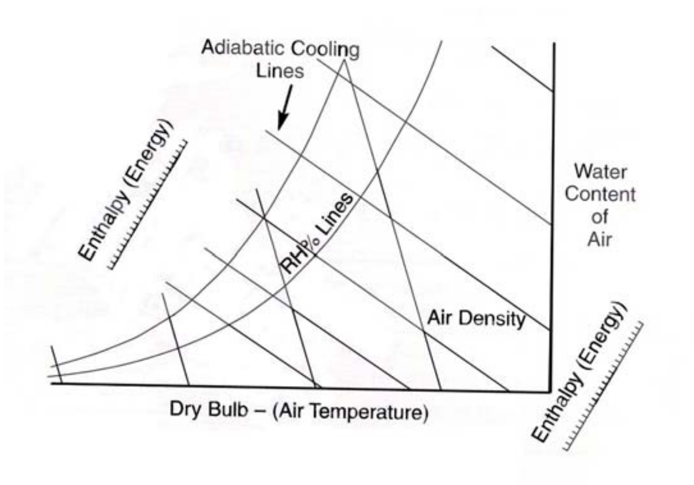
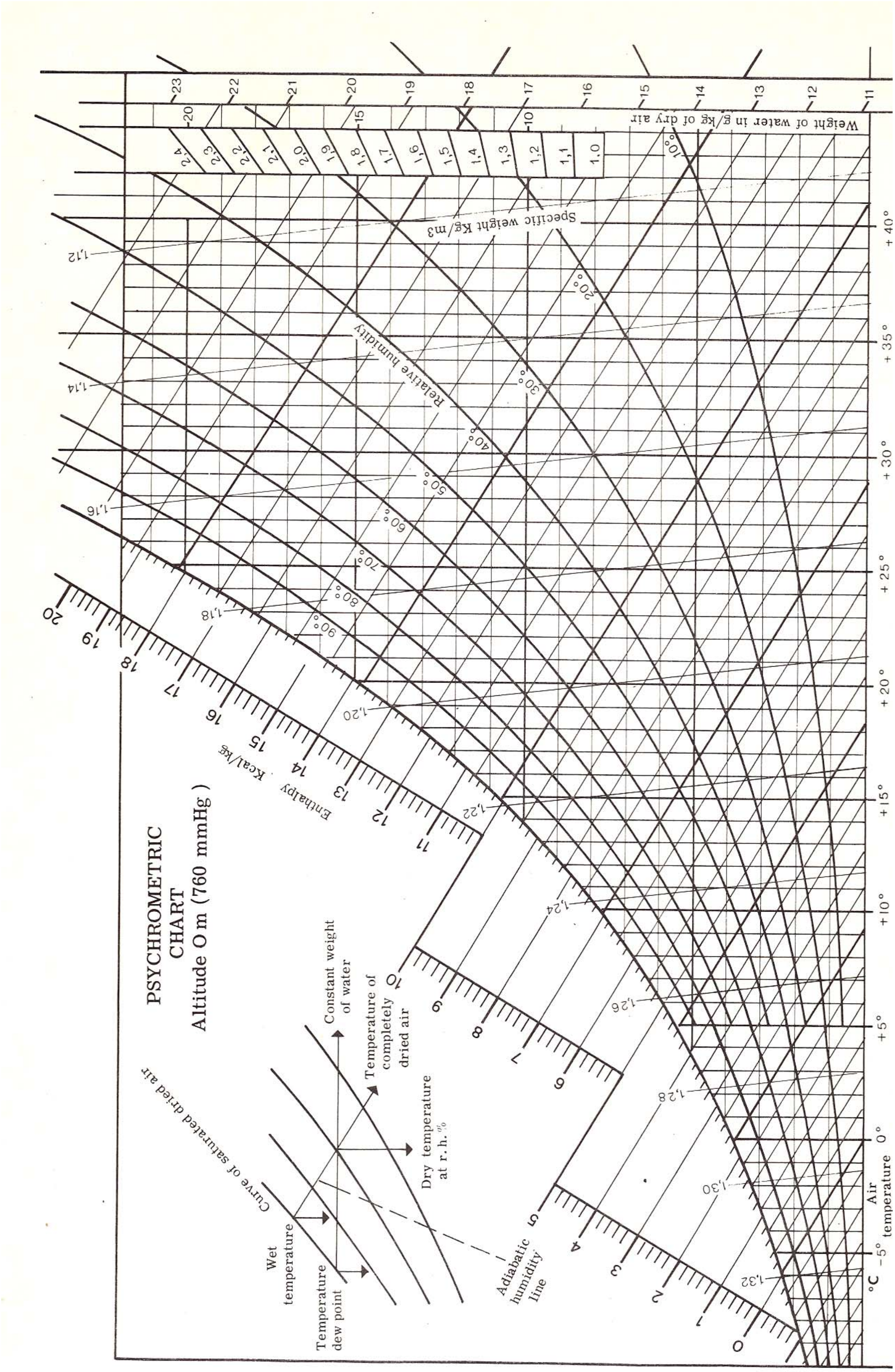


Figure 1: A simple psychrometric chart

The psychrometric chart is used to find the changes to air during drying. From that, the efficiency of the dryer can be calculated. The following examples show how it is used.
Using Figure 2, find:

1 the absolute humidity of air which has 50% RH and a dry-bulb temperature of 60°C
2 the wet-bulb temperature under these conditions
3 the RH of air having a wet-bulb temperature of 45°C and a dry-bulb temperature of 75°C
4 the dew point of air cooled adiabatically from a dry-bulb temperature of 55°C and 30% RH
5 the change in RH of air with a wet-bulb temperature of 39°C, heated from a dry-bulb temperature of 50°C to a dry-bulb temperature of 86°C
6 the change in RH of air with a wet-bulb temperature of 35°C, cooled adiabatically from a dry-bulb temperature of 70°C to 40°C.



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Answers

1 0.068kg per kilogram of dry air (find the intersection of the 60°C and 50% RH lines, and then follow the chart horizontally right to read off the absolute humidity)
2 46.5°C (from the intersection of the 60°C and 50% RH lines, move left parallel to the wet-bulb lines to read off the wet-bulb temperature)
3 20% (find the intersection of the 45°C and 75°C lines and follow the sloping RH line upwards to read off the % RH)
4 36°C (find the intersection of the 55°C and 30% RH lines and follow the wet-bulb line left until the RH reaches 100%)
5 50-10% (find the intersection of the 39°C wet-bulb and the 50°C dry-bulb temperatures, and follow the horizontal line to the intersection with the 86°C dry-bulb line; read the sloping RH line at each intersection (this represents the changes that take place when air is heated prior to being blown over food))
6 10-70% (find the intersection of the 35°C wet-bulb and 70°C dry-bulb temperature, and follow the wet-bulb line left until the intersection with the 40°C dry-bulb line; read sloping RH line at each intersection (this represents the changes taking place as the air is used to dry food; the air is cooled and becomes more humid as it picks up moisture from the food).

When food is placed in a dryer, there is a short period during which time the surface heats up. This is followed by two distinct phases, the constant rate and the falling rate. In the constant rate phase, water is removed from the surface of the food by evaporation. If the condition of the air (the temperature and relative humidity) within the dryer is constant, the water is evaporated at a constant rate. This is shown as the steep straight line on the graph (figure 3). As drying proceeds, water has to be removed from the inside of the food. This becomes more and more difficult as the water has to travel further through the food from the centre to the outside from where it is evaporated. The drying rate slows down, which is known as the falling rate period. On the graph this is seen as the shallower part of the curve. Eventually no more moisture can be removed from the food and it is said to be in equilibrium with the drying air (the final part of the curve where it flattens out). During the falling rate period, the rate of drying is mainly controlled by the chemical composition and physical structure of the food. The temperature of the drying air is also important during this phase as hot air helps the moisture inside the food to move towards the surface.

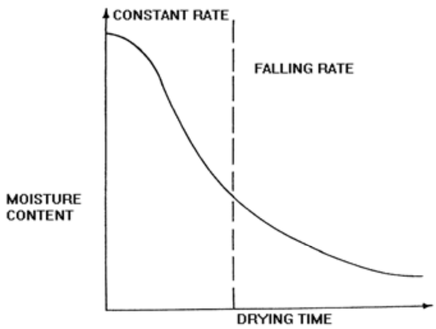

Figure 3: Drying rate

Measuring the drying rate

If a new type of dryer is to be used, or if a different type of food is to be dried, it is necessary to carry out a few experiments to find the rate of drying. The information can then be used to find the time that the food should spend in the dryer before the moisture content is low enough to prevent spoilage by micro-organisms. The rate of drying also has an important effect on the quality of the dried foods and (in artificial dryers) the fuel consumption. To find the rate of drying you will need a clock or watch and a set of scales.

Weigh the food, place it in the dryer and leave for 5-10 minutes. Remove the food, reweigh it and replace in the dryer. Continue like this until the weight of the food does not change any more (it has reached a constant weight and all the moisture has been removed).

The interval between weighings can be increased when the changes in weight start to become less. You should also make a note of the wet and dry bulb temperatures of the air inside the dryer and the air outside. Plot the results on a graph (see Figure 3). You will see the two distinct phases of drying - the 'constant' and 'falling' rate periods. During the constant rate of drying the surface of the food remains wet which means it can easily be spoiled by moulds and bacteria. During the falling rate period, the surface is dry and the risk of spoilage is much smaller. For the best quality dried foods, it is essential to reach the falling rate period as quickly as possible as this minimises the potential for spoilage. However, it is also important not to reach this point too quickly because a process known as case hardening may take place (see the box below).

The information collected from a drying rate experiment can be plotted in a different and more useful way by plotting the moisture content against the change of moisture with time (the rate of drying). This produces a type of graph that is shown in figure 4. Drying rate is obtained by calculating the drying rate for each 10 minute period as follows:

$$\text{Drying rate} = \frac{\text{initial weight - final weight}}{\text{time interval (eg 10 minutes)}}$$

The moisture content of both the fresh food and the final dried food can be found by weighing the food, heating at 100°C in an oven for 24 hours and reweighing. The moisture content is found as follows:

$$\text{Moisture content (\%)} = \frac{\text{initial weight - final weight x 100}}{\text{initial weight}}$$

Other values of moisture content during the drying period can be found by relating these two results to the weights of food recorded during the drying experiment and applying similar factors to intermediate weights. Figure 4 gives two important pieces of information:

1. The actual drying rate during the constant rate period which shows how efficient the dryer is.
2. The final moisture content of the dried food which shows whether it will be stable during storage.

A typical drying rate for a solar dryer would be 0.25kg/hr. This depends on the design of the dryer and the climate. Artificial dryers dry at a faster rate. Typical values are 10-15 kg/hr. If the drying rate is lower than this, the air temperature or speed is too low and/or the RH is too high. This can be checked by the temperature measurements made during the experiment and by using the psychrometric chart. Normally the air in the dryer should be 10-15ºC above room temperature in solar dryers and 60-70ºC in artificial dryers. The RH of air entering the dryer will vary according to local conditions, but should ideally be below about 60% RH.

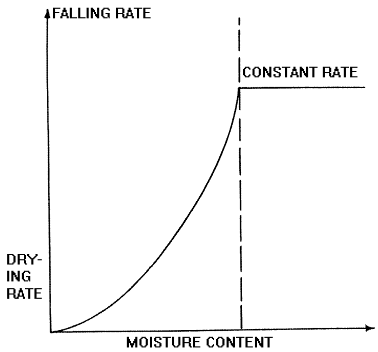

Figure 4: Drying rate/moisture content

Case hardening

Case hardening is a process that happens to some foods during drying. It is characterised by the formation of a hard skin on the surface of fruits, fish and some other foods which slows the rate of drying and may allow mould growth. During drying, moisture from within the food moves from the centre to the outside of the food, where it is evaporated. If a tough crust develops on the outside, it will be impossible for the moisture in the centre of the food to escape. Case hardening is caused by drying too quickly during the initial (constant rate) period and can be prevented by using cooler drying air at the start of the drying process.

The importance of particle size

The main factor that controls drying rate is the rate that moisture can move from the interior of a piece of food to the surface. Therefore, the shorter the distance that moisture has to travel, the faster the drying rate. For this reason, wherever possible, products should be cut into small pieces prior to drying. Reducing the size also increase the surface area of the food in relation to the volume of the pieces, which increases the rate at which water can be evaporated from the food.

Stability and storage of dried foods

To ensure safe storage the final moisture content of the food should be less than 20% for fruits and meat, less than 10% for vegetables and 10-15% for grains.
The stability of a dried food during storage depends on its moisture content and the ease with which the food can pick up moisture from the air. Clearly the risk of moisture pick up is greater in regions of high humidity. However, different foods pick up moisture to different extents (compare for example the effect of high humidity on salt or sugar with the effect on pepper powder -salt and sugar pick up moisture, pepper doesn't).

For foods that readily pick up moisture it is necessary to package them in a moisture proof material.

A low moisture content is only an indication of food stability and not a guarantee. It is the availability of moisture for microbial growth that is more important and the term ***water activity*** (a_w) is used to describe this. Water activity varies from 0-1.00. The lower the value the more difficult it is for micro-organisms to grow on a food.

Examples of moisture contents and a_w values for selected foods and their packaging requirements are shown in Table 1.

Food	Moisture content %	Water activity	Degree of protection required
Fresh meat Bread Marmalade	70 40 35	0.985 0.96 0.86	Package to prevent moisture loss
Rice Wheat flour Raisins Macaroni Marzipan Oats Nuts	15-17 14.5 27 10 15-17 10 18	0.80 0.72 0.60 0.45 0.75 0.65 0.65	Minimum protection or no packaging required
Toffee Boiled sweets Biscuits Milk Potato crisps Spices Dried vegetables Breakfast cereal	8 3.0 5.0 3.5 1.5 5-8 5 5	0.60 0.30 0.20 0.11 0.08 0.50 0.20 0.20	Packaged to prevent moisture dried uptake

Table 1: Food type characteristics and packaging requirements

Changes to food during drying

Case hardening is one of the changes that can take place while food is drying. Other changes include the loss of colour, flavour and nutrient content. Experiments with air temperature and speed can be used to select the best conditions for each food. The colour of many fruits can be preserved by dipping in a solution of 0.2-0.5% sodium metabisulphite or by exposing to sulphur dioxide in a sulphuring cabinet (Figure 5).

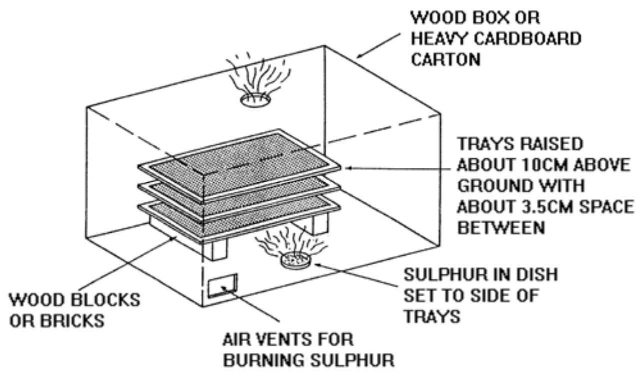

Figure 5: Sulphuring cabinet

Vitamin losses are often greater during peeling/slicing etc than during drying. Loss of fat soluble vitamins can be reduced by shade drying and loss of water soluble vitamins by careful slicing using sharp knives. Blanching of vegetables is necessary before drying and water soluble vitamins are also lost in this stage. It should be noted that drying does not destroy micro-organisms, it only inhibits their growth. Therefore, heavily contaminated fresh foods will become heavily contaminated dried and re-hydrated foods. It is essential to make sure that foods are not contaminated with micro-organisms before drying. Blanching is one method of reducing the levels of initial contamination. Thorough washing of fresh foods should be done routinely before drying.

Summary of small-scale drying equipment available

Solar dryers

Solar drying is popular with agencies and research stations. However, there are no small-scale solar dryers that are yet operating economically. There are a number of reasons for this:

- The amount of food lost in traditional drying is often over estimated (people report the worst case and the average amount).
- The loss of quality is not necessarily reflected in lower prices. People are willing to pay nearly the same amount for discoloured or damaged foods and there is therefore no incentive for producers to risk higher amounts of money in a dryer when there is not a great return.
- Different quality standards are applied by agencies and rural people. It is not necessary to achieve export quality for sale in rural areas.
- Dryers are only needed in villages if the weather is unsuitable for traditional methods. If these conditions are not very common, the dryer will not be needed. Even short periods of sunshine are enough to prevent serious crop losses. Some producers wait for sunshine rather than risk the expense of using a dryer. The food is then either spoiled or the dryer is not big enough to handle the amounts involved.
- Other methods are available to preserve the food if it rains during harvest, for example the harvest can be delayed, food can be stacked in a way which prevents it from getting wet, or small amounts can be dried over a kitchen fire, or mixed with dry crop.
- Some benefits of proper drying (for example absence of mould, and better milling characteristics of grains) cannot be seen and there is therefore no increase in value of the food.

Other disadvantages of both solar and mechanical dryers include greater space and labour requirements than traditional methods (for example loading, unloading of trays). These costs are given lower value by agencies than by villagers.

Solar dryers operate by raising the temperature of the air to between 10-30ºC above room temperature. This makes the air move through the dryer and also reduces its humidity.

There are advantages to solar drying as follows:

- The combination of higher temperature, movement of the air and lower humidity increases the rate of drying.
- Food is enclosed in the dryer and therefore protected from dust, insects, birds and animals.
- The higher temperature deters insects and the faster drying rate reduces the risk of spoilage by micro-organisms.
- The higher drying rate also gives a higher throughput of food and hence a smaller drying area.
- The dryers are water proof and the food does not therefore need to be moved when it rains.
- Dryers can be constructed from locally available materials and are relatively low cost.

Types of solar dryer

Designs of solar dryer vary from very simple direct dryers (for example a box covered with plastic to trap the sun's heat) to more complex indirect designs which have separate collectors and drying chambers. As the name suggests, the collector collects and concentrates the suns rays and heats up the air within the dryer. The hot air is then forced ointo the drying chamber where it removes moisture form the food. The most common type of collector is a bare galvanised iron plate which is painted matt black. These give a temperature increase of 10ºC and increase the air speed to about 5m/s.

The collectors are covered with a transparent material to ensure uniform airflow. Glass covers are best but they break easily, are heavy and expensive. Plastic often has poor stability to sunlight and weather, but is about 10% of the weight of glass and does not break. The best types of plastic are polyester and polycarbonate when available. Polythene is cheaper and more widely available but is not as strong and is less resistant to damage by light and weather.

The drying food can either be exposed to the sunlight (in direct systems) or dried indirectly by passing heated air over the food. In the indirect system the drying food is shaded, which helps to retain the colour and nutrients that are light-sensitive. Direct systems are used for food such as raisins, grains and coffee where the colour change caused by the sun is acceptable. However, most foods need indirect systems to protect the colours in the food. Other types of dryers use fans to blow the air over the food but this adds to the capital and operating cost and removes the advantages of dryers in rural areas which can not operate without electricity.

There are three basic types of solar dryer, each of which has many variations;

1. tent dryers (direct)
2. cabinet dryers (direct or indirect)
3. chimney dryers (indirect).

Each of these types of dryer uses natural air circulation although it is possible to fit an electric or wind powered fan to increase the flow of air through the dryer.

Tent dryers

This type of solar dryer consists of a ridge tent framework, covered in clear plastic on the ends and the side facing the sun, and black plastic on the base and the side in the shade. A drying rack is placed along the full length of the tent. The bottom edge of the clear plastic is rolled around a pole, which can be raised or lowered to control the flow of air into the dryer. Moist air leaves through holes in the top corners of the tent.

The advantages of this type of dryer are the low construction costs and simplicity of operation. However, like other types of solar dryer, there is relatively poor control over the RH of the air in the dryer and so, poor control over drying rates. It is also lightweight and fairly fragile when moved or in windy conditions.

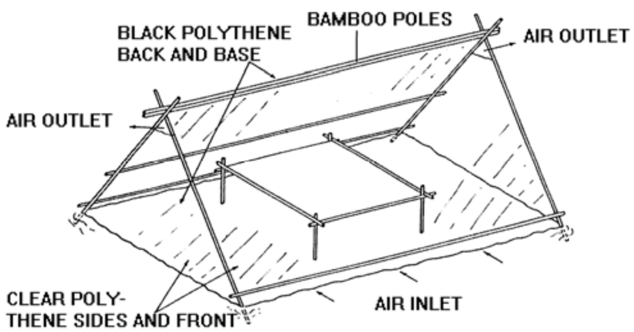

Figure 6: Tent solar dryer

Cabinet dryers

The basic design is an insulated rectangular box, covered with clear glass or plastic. There are holes in the base and upper parts of the box to allow fresh air to enter and moist air to leave. The inside of the cabinet is painted black to act as a solar collector. In indirect types, a flat plate is painted black and suspended in an insulated frame. Air is heated on both sides of the plate before passing into the drying cabinet. Food is placed on perforated trays within the cabinet and warm air from the collector rises up through the food and leaves through the top. The length of the cabinet is approximately three times the width to prevent shading by the sidewalls.

The sides can be made from board or mud-coated basket work. Larger models can be made from mud, brick or cement. The insulation can be wood shavings, sawdust, coconut fibre, dried grass or leaves, but should be at least 5cm thick to keep the inside temperature high. If insects are a problem, the air holes should be covered with mosquito netting. Drying trays should be made from basket work or plastic mesh. Metal should not be used as it can react with the acids in fruits and some vegetables and cause off-flavours in the food. These type of dryers are used for fish, fruit, vegetables, root crops and oilseeds. They have capacities of up to 1 tonne.

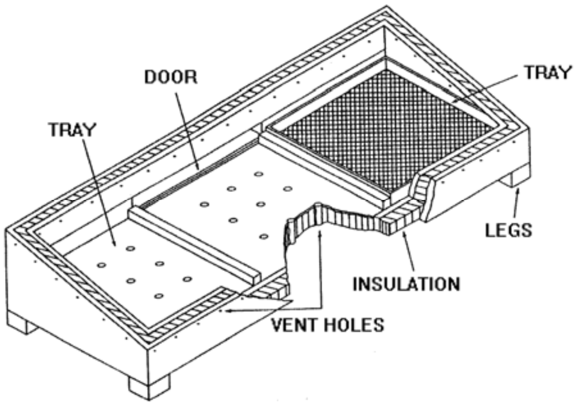

Figure 7: Cabinet dryer

Chimney dryer

This is a modified cabinet dryer in which a solar collector of black plastic or burnt husks is covered by clear plastic on a wooden framework. A black plastic chimney heats up the air above the exit to the dryer and therefore increases the airflow through the dryer.

Which type of dryer to choose?

The design of either type of dryer (direct or indirect) must be adapted to suit local climatic conditions, the products to be dried and available construction materials.
Factors to consider when selecting a dryer are described in the box below. A checklist questionnaire at the end of this brief is a useful tool to help decide whether a solar dryer is a practical option in your locality.

Factors to consider when selecting a dryer

- **Local climate – is it wet or dry.** How many hours of sunshine are there in a day? In Afghanistan, the climate is generally dry and there is a lot of sunshine, such that sun and solar drying are easy to do.
- **The availability (and cost) of materials to build a dryer.** This is linked to the end-use of your fruit and vegetable. If you can sell the product for a good price, it may be worth investing in a slightly more expensive dryer. Can you join together with other women who will use the dryer? You could all contribute to the building costs of the dryer and make a good dryer that will be well used by your community.
- **The availability of local craftsmen or workmen to build a dryer.** You will need somebody to follow basic plans and construct the dryer. It is useful if they understand how the dryer works as they will be able to adapt the plans to your local conditions and advise you on how to use it.
- **The amount of fruit and vegetables you want to dry.** If you have a large volume of fruit and vegetables to dry, it is best to build several small dryers that can be used at the same time, rather than trying to make a big dryer that will accommodate all your product. That way you have more control over the drying conditions and will get a better quality product. If any of the dryers are broken, for instance if the plastic cover gets damaged, you will still have others that you (and your neighbours) can use. You can dry more than one product at the same time.
- **The value of the fruit or vegetable you are drying.** Is it a high value product that you will be able to sell for a good price or is it a low value product that you will consume at home. This will help you to decide how much money you can afford to invest in buying a dryer.

Artificial (mechanical) dryer

Artificial dryers use fuel to increase the air temperature, and reduce the RH and fans to increase air speed. They give close control over the drying conditions and hence produce high quality products. They operate independently of the weather and have low labour costs. However, they are more expensive to buy and operate than other types of dryers. In some applications, where consistent product quality is essential, it is necessary to use mechanical dryers.

Light bulb dryer

This consists of an electric light bulb inside a wooden box. If electricity is available this is a simple, low cost dryer which may be suitable for home preservation. The capacity is very small and it is not likely to be useful for income generation. The bottom of a box is painted black, or covered in soot or black cloth. The sides are covered in shiny material (for example aluminium paint) to reflect the heat onto the black surface. Air circulates by natural convection in a similar way to the solar cabinet dryer, but in this case the dryer can operate all night as well as all day.

Cabinet dryer

The design is similar to the solar type but in this case the heat is supplied by burning fuel or electricity. If electricity is available, a fan can be used to increase the speed of air moving over the food and therefore increase the rate of drying. To be economical it is likely that this type of dryer should be relatively large (1-5 tonnes). These are successfully used for drying herbs, tea and vegetables.

Practical Action has developed a range of drying systems including a small, low-cost industrial type which can be fabricated in countries of intended use. Its small size makes it suitable for decentralised use in crop-growing areas. The price at about US$ 3,000, is substantially lower than for standard, commercially available units.

The small unit is a semi-continuous drying cabinet with hot air supplied by an indirect heater-blower unit (see the Technical Brief on Tray Dryers). Intended for round-the-clock operation, the semi-continuous tray dryer is designed for maximum fuel efficiency. It takes about four hours for the first (bottom) tray to dry: after that, it can be removed, the remaining trays lowered, leaving a space at the top for a tray of fresh material. Trays can then be removed every twenty minutes.

Silo dryer

These dryers consist of trays or tanks containing a deeper layer of food than those found in cabinet dryers.

They have a larger capacity and are often used for grain drying, where the amount of water to be removed is smaller than for example fruits and vegetables, but the quantities involved are larger.

There is considerable scope for the use of small dryers that combine the low cost of solar heating with better control of mechanical dryers.

References and further reading

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Tray Dryers, Practical Action Technical Brief
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Catalogue of small scale food processing equipment. FAO Thailand
http://www.fao.org/docrep/X5424E/x5424e00.HTM
Meat drying – includes diagrams of how to construct solar dryers.
ftp://ftp.fao.org/docrep/fao/010/ai407e/ai407e08.pdf
FAO Solar drying equipment. Includes list of suppliers of dryers.
http://www.fao.org/sd/Teca/tools/lst/LSTP19_en.html

Equipment suppliers
Note: This is a selective list of suppliers and does not imply endorsement by Practical Action.

This website includes lists of companies in India who supply food processing equipment.
http://www.niir.org/directory/tag/z,,1b_0_32/fruit+processing/index.html

Dryers

Acufil Machines
S. F. No. 120/2, Kalapatty Post Office
Coimbatore - 641 035
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