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Dehydration

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Walnuts must be dried to 8 percent wet-basis moisture soon after harvest to maintain optimal storage life and quality. Before 1920 walnuts produced in California were dried on wooden trays in the open sun. Sun-drying was labor-intensive and required up to 12 days in poor weather. By 1929 half of the crop was dried in heated air dryers. Drying with heated air dryers was about six times faster than sun-drying. The three main types of dryers at that time were open-bin dryers (manufactured by Mahoney), bin dryers with air recirculation and airflow-reversing capability (Ward), and rotary-drum dryers (Bishop). In the late 1930s the Brown multistage dryer was popular.

TYPES OF DRYERS CURRENTLY USED

Today the most common dryers are the stationary bin, pallet bin, trailer, and modified grain trailer. Table 34.1 lists the advantages and disadvantages of these four drying systems.

Stationary Bin Dryers

Usually built with a holding capacity of 25 tons, a stationary bin dryer is divided into a number of individual bins, each with a 1- to 5-ton capacity (fig. 34.1).

Figure 34.1 A stationary bin dehydrator.

Table 34.1 A comparison of walnut-drying systems typical in California.

	Stationary bin	Pallet bin (including forklift)	Trailer	Grain trailer
Cost to purchase	High	High	Moderate to high	Low
Labor requirement	Low	Moderate	Low	Low
Ability to handle small (less that 1-ton) lots of nuts	Good, depending on bin size	Best	Poor	Poor
Convenience for bulk deliveries to handler	Good	Poor	Poor	Best

The expanded metal floor of the bin is sloped at about a 30-degree angle so that nuts fill the bin with a minimum of raking. A bin is usually 5 to 7 feet deep. Nuts are loaded into the top of the bin and unloaded through a door at the bottom. Belt conveyors are used to move nuts into and out of the dryer. Air heated to 110°F (43°C), the maximum allowable temperature for walnuts, is blown through the nuts at a rate of 15 to 25 cubic feet per minute (cfm) of air per cubic foot of nuts in the bin.

Pallet Bins

A pallet bin system (fig. 34.2) consists of 4- to 6-foot-high expanded metal-bottomed pallet bins that are filled with walnuts. The floor of some bins can be sloped so nuts can be removed through a sliding door at the bin bottom. Some bins have a horizontal floor and are unloaded with a forklift attachment that tips the bin. Bins are placed over an underground air-distribution chamber. Air heated to 110°F (43°C) is blown through the nuts at rates similar to those used for stationary bins. After drying, the nuts are loaded into plywood bins or bulk trucks for transport.

Trailer dryers

Figure 34.3 shows a trailer dryer, which operates with the same air temperature and flow rates as other dryers, but it holds nuts in a four-wheeled trailer during drying. The trailer is 5 to 6 feet deep and holds 5 to 10 tons of nuts. Heated air from a portable fan and burner is delivered to the nuts through a screen-covered floor plenum in the bottom of the trailer. The nuts can be hauled to the processor in the trailer, eliminating some nut-handling operations needed with other dryer types. Expensive models are equipped with brakes, for safety on the road, and some are self-unloading.

Modified Grain Trailers

The hopper-bottomed grain trailer (fig. 34.4), holds 12 to 13 tons of dried nuts when fitted with 3-foot-high wall extensions. An air duct, portable fan, and burner unit (to supply heated air) are needed to convert a grain trailer into a walnut dryer. When these dryers are made from used grain trailers, which already have brakes, they can be purchased and modified for about half the cost of new trailer dryers fitted with brakes.

PRINCIPLES OF DRYING

Our understanding of walnut drying has come through laboratory and field experiments coupled with mathe-

Figure 34.3 A trailer dehydrator.

Figure 34.2 A pallet bin dehydrator.

Figure 34.4 A modified grain trailer.

matical models that simulate the drying process. This section covers the basics of drying and makes some suggestions about dryer design and management.

Moisture Content

The wet-basis moisture content of a given material is defined as the weight of water in the material divided by the total weight of the material. Table 34.2 gives the weight of walnuts in a 4-by-4-by-6-foot bin at several average moisture contents. A total of 831 pounds of water is removed from walnuts by drying them from 35 percent moisture to 8 percent moisture. One concern to dryer operators is overdrying, which results in lost revenue because less product weight is delivered. Overdrying by 2 percent, which is fairly common, results in a loss of 43 pounds per ton of dried walnuts.

Moisture variability. The moisture content of walnuts before drying varies according to harvest date and ambient weather conditions. Within a given lot, the moisture content of individual walnuts can vary significantly. An example of moisture variability, shown in table 34.3, gives the ranges of individual nut moistures for early-season Ashley walnuts before and after drying in a pallet bin dryer. The average initial moisture was 23.7 percent, with individual nut moistures ranging from 15 percent to 55 percent. The average final moisture (from the top of the bin) was 6.2 percent, with individual nuts ranging from 3 percent to 13 percent.

This level of moisture variability requires collecting a sample of 20 to 30 nuts for determining moisture at the end of drying. Sampling just 5 nuts, for example, may give an inaccurate estimate of the bin average. Sampling location is also important, as this chapter will discuss later.

Table 34.2 Weight of walnuts, with various moisture contents, in a 4-by-4-by-6-foot bin.

Average moisture (%)	Difference from total walnut weight (lb)	Weight at 8% moisture (lb)
35	2,831	831
8	2,000	0
6	1,957	–43
4	1,917	–83
2	1,878	–122

Table 34.3 Distribution of moisture contents of 100 Ashley walnuts.

Before drying		After drying	
Moisture range (%)	Percentage of sample	Moisture range (%)	Percentage of sample
10–15	0	3–4	1
15–20	11	4–5	23
20–25	27	5–6	37
25–30	28	6–7	13
30–35	12	7–8	13
35–40	12	8–9	4
40–45	7	9–10	3
45–50	0	10–11	2
50–55	3	11–12	2
55–60	0	12–13	2

Equilibrium moisture content. The stable moisture content walnuts reach if exposed to a constant air temperature and relative humidity is called the equilibrium moisture content. Figure 34.5 is a graph of the equilibrium moisture content of walnuts as it relates to relative humidity. For whole nuts, 8 percent moisture corresponds to about 60 percent relative humidity at room temperature. Nuts exposed to air at 110°F (43°C) and 20 percent relative humidity, typical drying conditions, reach 4 percent moisture content if left in the dryer too long.

Equilibrium moistures for the shell and kernel differ. When walnuts are removed from a dryer, shell moisture is normally higher than that of the kernel. Moisture content measurements are always based on the whole nut. Using the kernel alone to represent the whole nut results in false low readings.

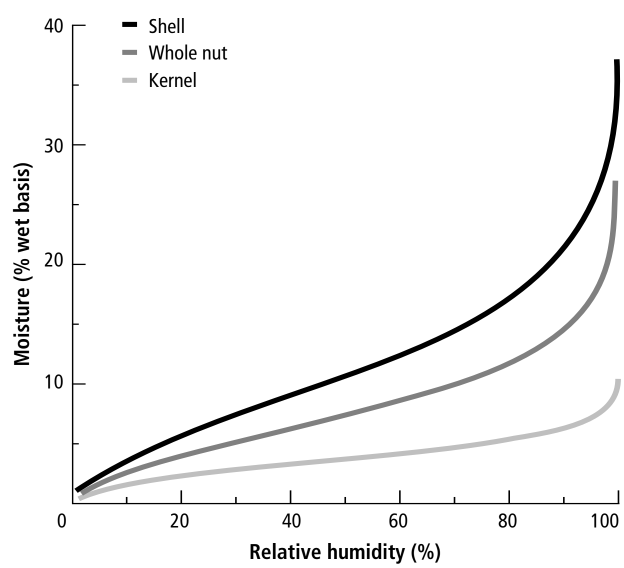

Figure 34.5 Equilibrium moisture curves for Franquette walnuts at 72°F (22°C).

BIN DRYING

Drying in bins usually results in a moisture difference from bottom to top of the bin. Average moistures measured at various times at the top, middle, and bottom of a 4-foot-deep laboratory bin dryer are shown in figure 34.6. Notice that the initial moistures are fairly uniform at the start of drying; however, after 17 hours, a gradient forms from the bottom (air inlet) to the top (air outlet) of the dryer. Nuts on the bottom are significantly overdried. After 43 hours the average moisture is near 4 percent, and there is still a slight moisture gradient in the bin.

In commercial dryers walnuts dry as if they were in a number of single layers. The nuts in the lowest layer release their moisture to the drying air, which increases its humidity and decreases its temperature. The second layer dries at a slower rate than the first because the air is at a lower temperature and higher humidity. The process continues as the air passes through the bin, giving rise to a moisture gradient from bottom to top.

In figure 34.7 contour lines represent constant moisture predicted by a mathematical model of a six-foot-deep stationary bin dryer and a pallet bin dryer. Drying has progressed until the moisture is 8 percent on top. The lines of constant moisture remain parallel with the bottom surface in the pallet bin. They are parallel near the bottom of the stationary bin and become curved farther away from the bottom because of the nonuniform airflow within the bin. The difference in moisture between the bin top and bottom will vary with airflow and inlet air humidity; the difference is smaller as inlet airflow or humidity is increased.

Because nuts near the top of a bin are the last to dry, sampling for nut moisture at the top of a bin will give a high estimate of the average moisture within the bin. If sampling from stationary bins, take the sample in the middle portion of the top—this will prevent you from sampling the slow-drying spots near the front and back.

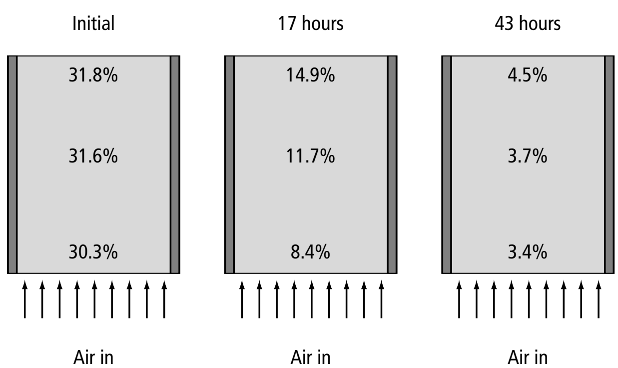

Figure 34.6 This figure shows the difference in average moisture in various parts of a bin dryer during a drying cycle.

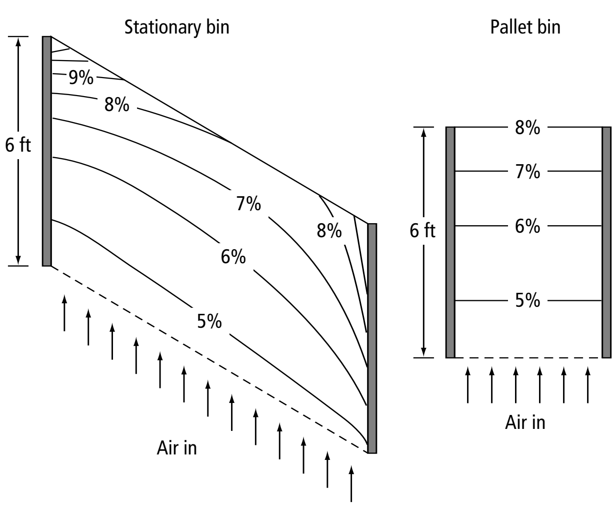

Figure 34.7 These drawings show contours of constant moisture in stationary and pallet bin dryers.

Table 34.4 Wet-basis nut moisture at the top of a bin when average moisture is 8 percent.

Initial nut moisture (%)	Air flow rate (cfm/cu ft) 12.5	25	37.5
15	11.6	9.9	9.4
25	14.0	11.3	10.4
35	16.7	12.6	11.1

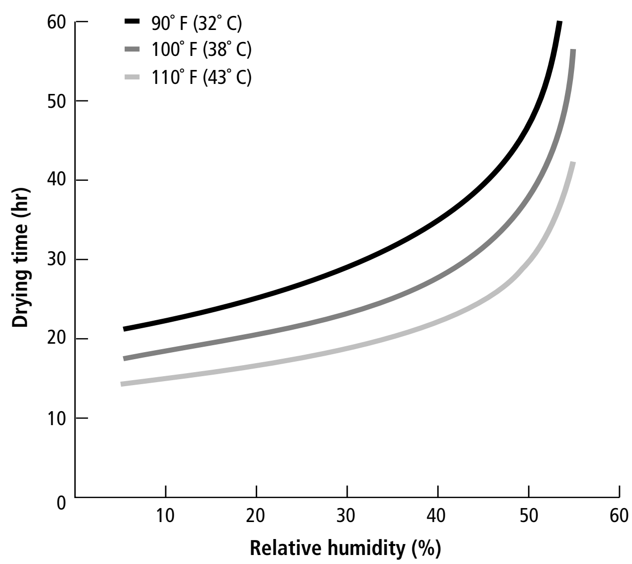

Figure 34.8 This graph shows the drying time needed to decrease the average moisture of top nuts from 25 to 8 percent. The time is a function of air temperature and humidity. Airflow was 20 cubic feet per minute per cubic foot, and the bin was 6 feet deep.

The amount of moisture difference between nuts at the top of the bin and the average nut moisture is affected by air rate and initial moisture content of the walnuts. Table 34.4 shows that the difference is highest with a low air rate and a high initial moisture. Air rate should be about 30 cfm per cubic foot to minimize differences. Initial moisture cannot usually be controlled, but operators must remember that higher initial moistures cause the top nuts to be wetter at the end of drying than they are at low initial moistures. Dryers with deep beds tend to have low air rates, measured in cfm per cubic foot, and this often causes nut moisture at the top to be much greater than the average moisture of the bin.

Dryer operators can change dryer performance by controlling air temperature, humidity, and flow rate. Air temperature can be controlled by regulating the flow of gas to the dryer's burner; humidity is controlled by regulating the amount of air that is recycled from the dryer exhaust back through the burner. Figure 34.8 shows the effect of drying air temperature and humidity on drying time. Increasing the air temperature decreases drying time. At 20 percent relative humidity, increasing the air temperature from 90° to 110°F (32°C to 43°C) reduces the drying time by about one-third, from 25 hours to 17 hours. As mentioned, air temperature should not exceed 110°F (43°C). Temperatures above this darken kernels and reduce their storage life. As the air humidity into the bin approaches 55 percent, the drying time increases dramatically because the humidity is close to the equilibrium moisture of 8 percent. Figure 34.9 shows the relationship between drying time and humidity. Recirculating more than about 50 percent of the drying air causes unacceptably high humidity in the drying air; the result is long drying time.

Field and laboratory tests have shown that increasing the airflow rate per volume of walnuts decreases drying time. Doubling the air flow rate decreases drying time by about one-third. Figure 34.10 shows that airflows above 50 cfm per cubic foot cause little reduction in drying time. However, increasing the airflow increases energy use per ton of nuts dried. Airflow near 30 cfm per cubic foot strikes a good balance between dryer capacity and fan energy costs, which increase rapidly with increasing airflow. Airflow rate is primarily determined by fan selection. It can be increased by (1) increasing the fan speed to the maximum recommended by the manufacturer, (2) decreasing the number of bins on the dryer, and (3) dropping the level of walnuts in the bins.

Average air speed through a bin can be estimated by two methods. One simple and fairly accurate method is to determine which of several readily available paper materials, placed above top nuts, will be lift-

Table 34.5 Simple method of air speed measurement.

Type of paper	Air speed that will cause paper sheet to float (ft/min)
Newspaper (½ sheet)	40–50
Newsmagazine cover	60
Half of manila folder	80–90
Side of large breakfast cereal box	150

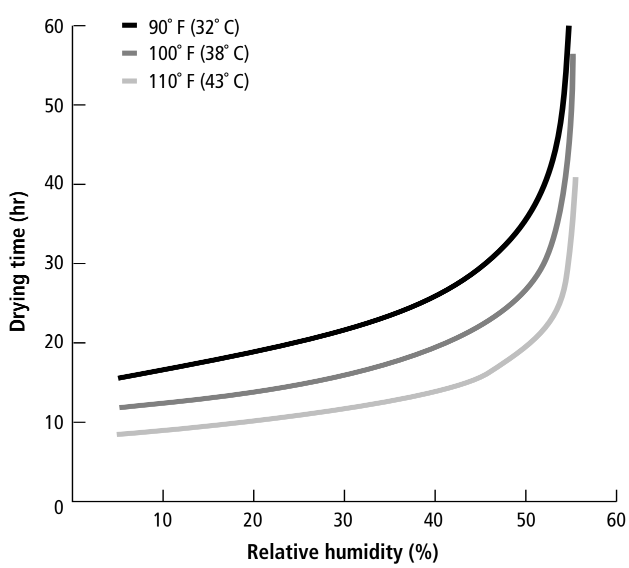

Figure 34.9 This graph shows the time needed to dry a single walnut to a moisture content of 8 percent at three different air temperatures and varying humidity.

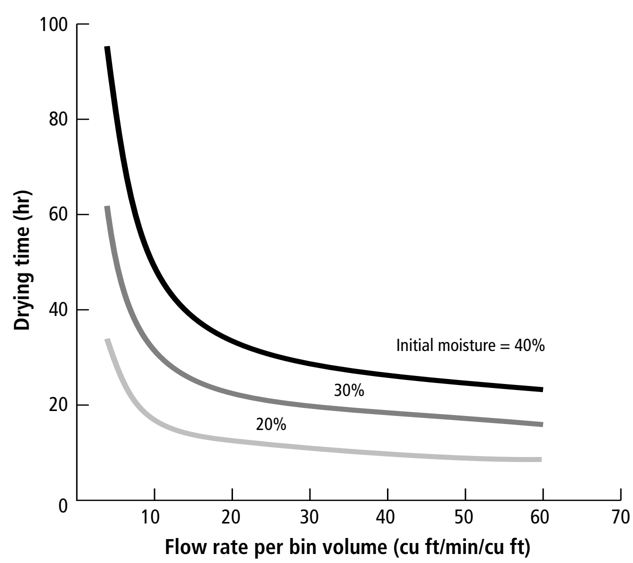

Figure 34.10 In this graph the time needed to decrease the moisture of top nuts from 25 to 8 percent is shown as a function of airflow and initial nut moisture. The bin was 6 feet deep.

ed by the exiting air. Table 34.5 shows the relationship between air speeds through walnuts and ability of the air to lift papers of various weights. The airflow per unit volume is calculated by dividing the air speed by the depth of nuts in the bin.

Airflow can also be estimated by measuring static air pressure in the air-supply duct just below the nuts. Table 34.6 lists airflows per walnut volume associated with various static pressures and bin depths. For example, to obtain 30 cfm per cubic foot in a 6-foot-deep bin requires 2.7 inches of water or static pressure. Table 34.7 gives horsepower per ton of dried walnuts required to produce the given airflows. These requirements assume that the system is well designed and that the nuts furnish primary resistance to flow. Notice that requirements become large at the highest airflows and bin depths.

The moisture content of nuts as they are brought in from the field dramatically affects drying time. Nuts harvested at the beginning of the season may have a moisture content of 30 to 40 percent and require 24 to 36 hours to dry (fig. 34.10). At the end of the season, nuts may reach the dryer at nearly 8 percent moisture and require very little drying.

Table 34.6 Static pressure (in. of water) required for given airflows and bin depths.

Airflow (cfm/cu ft)	Bin depth (ft)			
	4	5	6	8
10	0.11	0.21	0.36	0.81
15	0.24	0.45	0.75	1.70
20	0.40	0.76	1.30	2.90
25	0.61	1.20	1.90	4.40
30	0.85	1.60	2.70	6.10
35	1.10	2.10	3.60	8.10
40	1.40	2.70	4.60	10.30

Table 34.7 Horsepower per dry ton required for given air flows and bin depths.

Airflow (cfm/cu ft)	Bin depth (ft)			
	4	5	6	8
10	0.022	0.042	0.070	0.16
15	0.070	0.13	0.22	0.50
20	0.16	0.30	0.50	1.10
25	0.30	0.56	0.95	2.10
30	0.50	0.95	1.60	3.60
35	0.78	1.50	2.50	5.60
40	1.10	2.10	3.60	8.10

DRYER DESIGN

Designing a walnut dryer begins with estimating the holding volume needed. Determine the typical maximum tonnage that will be harvested in a day. Multiply the tonnage by 80 cubic feet per ton to calculate dryer holding volume. You may want to adjust this capacity after considering that walnuts harvested during the first part of the season may take more than 24 hours to dry. Also, some designers provide extra capacity to hold walnuts so they can equalize in moisture after drying and accumulate until the batch weighs at least 25 tons, the typical weight a semi-trailer and tractor hauls from the ranch to the processor.

Bin layout can be established after determining the holding volume, typical lot size, and maximum walnut depth in the dryer. Divide the holding volume by the maximum nut depth to determine the floor area occupied by the dryer. The nut height usually ranges from 5 to 7 feet. The dryer area will be divided into bins to hold 1- to 5-ton lots. The bins are usually arranged in lines to allow the use of a common plenum chamber for supplying hot air.

Total airflow (in cfm) to the drying bins is calculated by multiplying the dryer volume in cubic feet times the airflow per bin volume desired. Most dryers operate in the range of 20 to 30 cfm per cubic feet of bin volume.

To select a fan, you need to specify both the airflow capacity and the pressure that the fan must operate against. Use the airflow rate and the depth of walnuts with table 34.6 to determine the pressure through the nuts. Add to this the pressure drop in the air-supply system. A well-designed air plenum and fan inlet have no more than ½ to 1 inch of pressure drop. Most walnut dehydrators use backward-inclined centrifugal fans. Some smaller units, especially the trailer dryers, use axial flow fans.

The plenum that supplies heated air to the bins should be sized to prevent unnecessary pressure losses. Air speed in the plenum should not exceed 1,500 feet per minute. The maximum cross-sectional area of the plenum is calculated by dividing the total airflow, measured in cfm, by 1,500 fpm. The plenum can have a smaller cross-sectional area along its length as air is diverted to successive bins. Most dryers are set up so that the air to each bin can be turned off individually, so the air plenum may need to be maximum size for a good portion of its length.

The burner must have the capacity to raise the temperature of the outside air to 110°F (43°C). In most areas of California, minimum temperature during the drying season is about 50°F (10°C). Size the burner by applying the following rule of thumb: 60,000 British thermal units per hour increase the temperature of 1,000 cfm by 60°F (16°C).

Because outside air temperature varies widely during the day, the burner must be able to efficiently produce widely varying amounts of heat. The ability of a burner to do this is indicated by its turndown ratio. Walnut dryers should be equipped with burners having a turndown ratio of at least 5:1.

Select a burner that is designed to operate in an airstream. These burners produce a short blue flame that does not radiate much heat. Yellow flames, which do radiate heat, can cause higher energy use than a blue-flame burner. The burner should be protected with an open grill for worker safety. A fine grate of expanded metal creates airflow resistance and increases electricity use by the fan.

Burners are usually regulated by an automatic control system that adjusts the fuel flow to maintain a constant air temperature. The control system should also include a high-temperature shutoff device and a flame-detection device. Some dryers have a clock that allows the operator to shut off the burner or both the fan and burner at a predetermined time. This is useful in preventing overdrying if a batch of nuts will be finished during the night, when no one is there to turn off the dryer. Final drying, if needed, can be completed the following morning.

Control systems for a few dryers have been designed to stop the drying process on the basis of the temperature of the air leaving the nuts. As the nuts dry, the temperature of the air leaving the nuts slowly increases. Some operators have found that when air leaving the nuts is only 5° to 7°F (3° to 4°C) cooler than the air entering the nuts, the batch is dry. The exact temperature setting varies with nut depth, airflow, and incoming nut moisture, but with enough experience an operator can use this guideline to estimate when drying is done.

Walnuts are brittle when dried and must be handled by belt conveyors or bucket conveyors. Augers will break shells. Equipment for handling dry nuts should have no large drops or should use decelerators where drops are necessary. Preventing overdrying reduces nut brittleness. Use air recirculation and moisture meters to reduce overdrying, or do not transfer nuts until the bottom nuts have had time to gain moisture.

ENERGY CONSERVATION

Walnut dryers use natural gas or propane for air heating and electricity for fan operation. A survey of walnut dryers indicated that an average dryer that has not been modified for energy conservation uses about 20 therms of natural gas or 22 gallons of propane per ton of dried nuts and 5 kilowatt hours of electricity per ton. Many dryers have been modified to halve their gas consumption and significantly reduce electricity use.

Incorporating air recirculation in a dryer can dramatically cut gas costs. When ambient air temperatures are low, recirculating 50 to 60 percent of the drying air will reduce energy use by up to 40 percent. Recirculating can be accomplished in dryers enclosed in a building by using an air duct or passage to connect the drying room with the fan room. The cross-sectional area of the air duct or passage should be about as large as the largest cross-sectional area of the plenum chamber underneath the drying bins. If a duct of this size is not feasible, use a smaller duct with a fan. In dryers covered with a roof only, drop plastic or canvas curtains from the eaves to form an air passage above the bins. This will direct a portion of the drying air back to the burner. The warmest air in the drying room is near the ceiling, so the recirculation duct should draw air from the top of the room. Figure 34.11 is a schematic representation of a recirculation system. Set up the system so that the amount of recirculation can be varied. This is usually done by installing large exterior doors next to the fan. The doors are opened to reduce air recirculation and closed to increase air recirculation. During the afternoon the outside air may be warmer than air coming from the nuts; at that time recirculation should be minimized. Generally, recirculation should begin when the air from the nuts is 10° to 15°F (6° to 8°C) warmer than outside air. In practice many operators close the doors next to the fan when they leave in the evening and open them when the air temperature rises the next day. If recirculation noticeably increases drying time, decrease the level of air that is returned from the dryer to the burner.

Field studies have shown that drying to 6 percent moisture instead of the acceptable 8 percent is very common. This increases drying time by about 7 hours. Extra drying time results in extra gas and electricity costs. Removing walnuts from the dryer at the right time, by following the walnut moisture measurement guidelines presented later, can significantly reduce energy costs, increase dryer capacity, and increase nut weight sold.

Another energy-saving practice is to turn the dryer off during the coldest hours of the day. Never turn the burner off during the afternoon, because the dryer uses the least amount of heat during these hours; turning off the burner slows drying and often causes the need for more drying during the night, when heating costs are highest.

Minimize burner energy losses by ensuring that the burner is designed to operate in a flow of air and that it is installed and operated according to the guidelines mentioned earlier.

Walnuts can be dried with unheated air, as are some grains. This eliminates gas use, but increases drying time by a factor of 5 to 7. Usually an unheated air dryer uses less airflow than does a heated air dryer, so fan energy use does not increase with use of unheated air drying. But unheated dryers must have a much greater holding capacity; therefore, capital costs increase.

FIRE SAFETY

Walnut dryers should be designed and operated to minimize fire hazard. A water supply should be close by and there should be convenient access to the air plenum, where many fires start. Broken nut pieces and fine material from hulls build up under the dryer. Combustible material that passes by the burner may ignite and be carried by the airstream to the fine dry material under the dryer; a fire starts. If dryers are operated unattended at night, they should be fitted with devices that detect excess temperature or smoke and alert those who can respond to the fire.

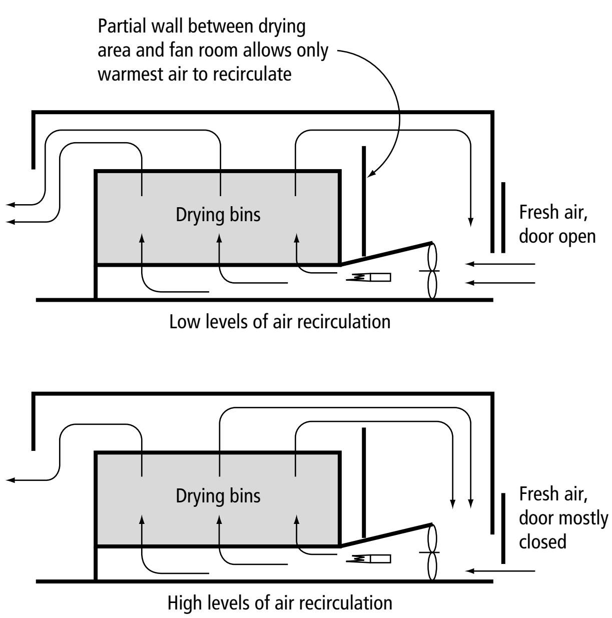

Figure 34.11 Airflow options in a recirculation system.

DRYER OPERATION

Stationary or pallet bin dryers are usually turned on when one-third to one-half of the bins are filled. The remaining bins are turned on as they are filled. This allows some drying to begin as quickly as possible but subjects the first group of bins to very high airflow. This causes nuts in them to dry in a shorter time than do nuts in other bins, which receive less airflow. For example, if the first group of bins is started 4 hours before the second group, nuts in the first group will be dry 6 to 10 hours (depending on incoming moisture) before the second group.

Determining the average walnut moisture content near the end of drying is difficult because moisture varies greatly within the bin. Nuts that have fallen naturally from the tree are much dryer than those that are shaken. Drying reduces moisture variation, but it is still significant near the end of drying. In a bin whose bottom slopes, moisture can vary from front to back of the bin (fig. 34.8). A representative nut sample requires randomly selecting 20 to 30 nuts for bench-top or portable moisture meters. One manufacturer makes an electronic moisture meter that can determine the average moisture of almost an entire bin of nuts. These meters eliminate the need for collecting nut samples and estimating the difference between top and bin average. Electronic meters can also be connected to the control system, which stops airflow when the nuts are dry.

Top nuts are almost always wetter than nuts in the bottom of the bin. This variation can be managed by remembering that the bin as a whole will be at 8 percent moisture when the top nuts are several percentage points wetter.

We do not recommend estimating final nut moisture by evaluating the brittleness of the membrane separating the nut halves. Most operators who use this method overdry the nuts. Use either portable moisture meters or the in-bin meter to determine average moisture accurately.

Some processors set a limit on the maximum moisture content of an individual nut. You will have to overdry the batch as a whole to ensure that the wettest nuts are below the limit, or let the moisture equalize by holding the nuts for 24 to 48 hours. Overdrying is expensive because less weight is sold to the processor, and it results in high energy use. However, nuts above the moisture limit may be considered off grade and significantly devalued. Even with in-bin moisture meters, some hand-sampling may be needed to evaluate variability from nut to nut.

After nuts have been dried, the next challenge is to maintain nut quality during storage. See chapter 33 for a discussion of rancidity and oxidation.