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Preservation of Fruits and Vegetables By Commercial Dehydration[1]

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INTRODUCTION

The investigation here reported was undertaken to determine certain physical principles and their application to dehydration problems in general. The project was not carried to the point where it was possible to consider the modifications necessary for the different varieties of fruits and vegetables. Factors leading to the deterioration of dehydrated products and the relation which the condition of the fresh material may bear to this deterioration are important phases of the problem not here considered.

PRESERVATION BY DEHYDRATION

Spoilage of raw food is due principally to the growth of molds and bacteria. This growth does not occur when the soluble solids are sufficiently concentrated through the reduction, by drying or by other means, of the water present in foods. Even if they are not killed, the molds and bacteria remain dormant and harmless in the absence

[1] Supersedes Department Bulletin 1335, Commercial Dehydration of Fruits and Vegetables.
[2] Died April 30, 1941.

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of a suitable medium for their growth. Changes in composition, flavor, and appearance, however, may also be brought about by the action of the enzymes present in practically all foodstuffs. As these natural catalytic bodies are not always inactivated by the treatment which stops mold and bacterial action, they must be considered in working out methods of dehydration.

The outstanding advantage of drying as a method of preserving foods is that the weight and bulk of the products are greatly reduced, thus making possible economy in storage and transportation (*15*).[3] The production cost of dehydration compares favorably with that of canning. Dried fruits and vegetables are almost as convenient for use in the home as the fresh products. They need no peeling or other preliminary treatment, and soaking and cooking can often be combined. Only the quantity required need be used when the package is opened; the rest will keep in good condition for a reasonable time.

DEHYDRATION INDUSTRY

"Dried," "sun-dried," "evaporated," and "dehydrated" are the terms most commonly used to describe dried products. Dried indicates drying by any means; sun-dried indicates drying without artificial heat; and evaporated implies the use of artificial heat. Evaporated refers more particularly to the use of artificial heat in driers depending for their air circulation on natural draft, while dehydrated implies mechanical circulation of artificial heat.

The commercial dehydration of fruits has reached a more advanced stage of development than has the commercial dehydration of vegetables, owing largely to the fact that the public is familiar with sun-dried and evaporated fruits, whereas it knows comparatively little about dried vegetables. The development of the commercial dried-fruit industry is shown in table 1, which gives production and values of the principal dried fruits for 1933, 1935, and 1937. These data, based on the Biennial Census of Manufacturers (*18*), do not include products of small local plants whose annual output is valued at less than $5,000.

During the World War 8,905,158 pounds of dehydrated vegetables, divided as follows, were shipped to the United States Army overseas: Potatoes, 6,437,430 pounds; onions, 336,780; carrots, 214,724; turnips, 56,224; and soup mixture, 1,860,000.

Table 2 shows the extent of the dried-vegetable industry in this country in 1919. All the vegetables were either dehydrated or evaporated. In the years immediately following 1919 the drying of vegetables declined rapidly, and for the last 10 years or more production has been comparatively small (table 1).

[3] Italic numbers in parentheses refer to Literature Cited, p. 41.

TABLE 1.—*Dried and dehydrated fruits and vegetables, United States production and value, 1933, 1935, 1937* [1]

Item	1933	1935	1937
Fruits:			
Apples:			
Pounds	53,287,649	70,388,563	63,934,564
Value	$4,168,623	$5,513,394	$4,578,099
Apricots:			
Pounds	83,006,505	49,176,457	70,643,022
Value	$6,820,530	$6,762,197	$7,773,286
Figs:			
Pounds	42,365,969	44,716,293	53,517,429
Value	$1,661,876	$2,233,901	$2,913,621
Peaches:			
Pounds	48,667,762	50,695,693	57,929,527
Value	$2,775,885	$3,747,882	$4,172,350
Pears:			
Pounds	(2)	14,098,736	10,771,060
Value	(2)	$1,006,088	$750,976
Prunes:			
Pounds	405,227,285	473,600,870	441,777,393
Value	$18,102,635	$19,957,682	$19,366,516
Raisins:			
Pounds	375,908,860	414,129,227	449,203,309
Value	$13,802,708	$17,422,741	$21,668,127
All others:			
Pounds	5,604,480	2,885,443	12,712,698
Value	$1,089,954	$261,860	$580,554
Total United States:			
Pounds	1,014,068,510	1,119,691,282	1,160,489,002
Value	$48,422,211	$56,905,745	$61,803,529
Total California:			
Pounds	(3)	[4] 1,035,727,776	[5] 1,082,704,952
Value		$52,441,397	$57,873,638
Vegetables:			
Value	$364,372	$161,885	$149,704

[1] From Biennial Census of Manufactures (*18*).
[2] Included under "all others."
[3] Not reported separately.
[4] Includes small production of apricots in Washington and raisins in Oregon.
[5] Does not include "all others."

TABLE 2.—*Quantity and value of dried vegetables processed in the United States, 1919* [1]

Vegetables	Quantity	Value	Vegetables	Quantity	Value
	Pounds			*Pounds*	
Beans	917,134	$116,091	Potatoes	7,253,230	$1,840,399
California	134,689	8,097	California	3,189,328	838,521
All other States	782,445	107,994	Oregon	774,087	176,806
Cabbage	19,901	13,684	All other States	3,289,815	825,072
Carrots	432,959	117,487	Spinach	40,989	41,352
California	312,207	88,568	Turnips	19,396	8,264
All other States	120,752	28,919	Other vegetables [2]	989,397	271,917
Celery	17,587	11,100	Soup mixture	655,228	222,361

[1] Fourteenth Census of the United States (1920), vol. 10, p. 79.
[2] From 500,000 to 1,000,000 pounds of dehydrated sweet corn is produced annually in Pennsylvania and Ohio. This is not included here.

DEHYDRATION PLANT

To be successful, a dehydration plant must be built where fresh materials are plentiful and reasonable in price. A diversity of products makes possible an operating season long enough to keep the overhead expenses down to the minimum. The products dried, however, should be limited to those for which a ready market exists. The only satisfactory method of operating is to contract for a sufficient acreage to take care of the needs of a plant at a price which will permit both the grower and the drier to make a profit.

SELECTION OF MATERIAL

Material to be dried must be carefully sorted so as to be free of mold, decay, and other defects that would lower the grade of the finished product. The stone fruits (apricots, peaches, cherries, and plums) must be sufficiently firm to permit mechanical pitting without tearing. Where they are prepared by manual labor, they must not be so soft as to stick to the trays. Apples and pears must not be so soft as to crush in the coring and peeling machines. Berries, cranberries, and grapes are usually dried whole. Fruit that needs trimming must be avoided, as it not only adds to the cost of operation, but also lowers the grade of the final product. Vegetables, such as beans (snap), cabbage, carrots, celery, corn, parsnips, potatoes, pumpkin, spinach, squash, and turnips, are sliced, shredded, diced, or cut in desired pieces before drying.

Dehydration does not improve the quality of fresh fruits or vegetables, nor does it provide for the satisfactory use of unsound products. At best the process can only conserve the original constituents of the foods, minus replaceable water.

PREPARATION OF MATERIAL

Careful handling reduces labor and waste. Bruised tissue is especially susceptible to discoloration and decay. Individual pieces prepared from good stock are more uniform and attractive than those from heavily trimmed stock.

Washing

Raw materials should be as carefully washed and cleaned for dehydration as for table use. Much of the washing machinery used in canning is suitable for use in dehydration plants. A rotary cylindrical washer equipped with a water-spraying system is very satisfactory for washing many types of products. Soft or easily broken fruits and vegetables may be washed by passing the trayed material between several sprays of cold water.

Grading for Size

The segregation of fresh fruits and vegetables according to size facilitates both the preparatory handling and the drying.

One type of grader consists of a perforated metal plate, 3 by 10 feet, or larger. The perforations are in sections of varying size, and the plate is inclined and mechanically agitated in order to insure an even flow of the material in one direction. The product is separated according to size by being passed through the perforations. Perforated plates are also used in stacks. Several plates, each stamped with holes of uniform size, the holes varying in size with each plate, are set one above the other, with 6 inches or more between plates. They are arranged so that the holes are progressively smaller from top to bottom.

Another grader sorts out easily rolling materials according to diameter. As a mechanically driven cable rolls the materials along an opening that increases in width, the product falls through and is collected according to size.

A grader based on the same principle passes the product down a chute the floor of which consists of rollers placed at increasingly greater distances apart. As the product rolls along the chute, it is separated in progression according to size.

Peeling

Manufacturers show a growing tendency to remove the skin from all fruits and vegetables before drying. Because of custom or the type of skin, some kinds, notably prunes and apricots, however, are rarely peeled.

Peeling may be done by hand or by specially designed machines. Many types of knives, with straight, curved or guarded blades, and hand-operated cutting machines are obtainable for peeling, trimming, coring, and otherwise preparing the material to be dried. Machines for peeling and coring both apples and pears in one operation are available.

Friction or rotary mechanical peelers are particularly well suited for handling roots and tubers. All peelers of this type depend upon the rasping effect of rough surfaces of cement, corundum, etc., forming some part of the lining of the peeler, when the product is rotated rapidly within the cylinder by a moving bottom. The material is introduced at the top and discharged by a side door. These machines are usually equipped with water sprays, which wash off the dirt and the particles of skin removed by the peeler. Other types make use of an open flame which chars the skin so that it can be brushed or washed off.

Several types of lye peelers are available. All depend upon immersing in or spraying with hot (190°- 200° F.) lye solution. The length of treatment must be determined for each batch of fruit. It should be long enough to permit the ready removal of skin by water sprays or by rubbing but must not injure the flesh of the product being peeled.

Trimming

Following the peeling, the fruit or vegetable must be inspected and all remaining skin removed with trimming knives, especially adapted to different products.

Checking

Lye is used to check the skins of prunes and grapes, in order to facilitate drying. The fruit is in contact with the hot lye solution long enough to break the skin by many minute fissures or checks, but not long enough to loosen it. The concentration and temperature of the lye bath are similar to those for lye peeling. After the lye treatment the fruit is carefully washed to remove all traces of the lye bath before further processing.

Subdividing

Fruits are sliced, cubed, shredded, or left whole. Vegetables are sliced, cubed, shredded, or chipped. The cutting is done by hand or by some one of the numerous machines on the market. Some of the machines consist essentially of rotating knives or cutting surfaces operated by hand or by power. In others the cutting surfaces are stationary, and the product is forced against the blades. Special machines for cutting beans are made. In the most satisfactory type of cubing machine the slices are cut, carried to a die, and forced through by a plunger.

Pitting and Seeding

Manufacturers find it desirable to pit or seed stone fruits, as pitted or seeded fruits dry more rapidly and sell more readily than those from which the pits or seeds are not removed. Machines for pitting, seeding, and paring most fruits are for sale by food-machinery manufacturers, but the greater part of dried fruits are pitted by hand.

Traying

After the raw material is prepared in the desired form, no time should elapse before traying and subsequent treatments preliminary to its being placed in the drier. No definite rule can be given for determining the quantity of material to be placed on a unit area of tray surface. Experience will soon show the operators how much will insure even, rapid drying. Many of the larger fruits must be trayed only one layer deep. Overloading trays must be avoided.

Trays should be light but capable of withstanding strain, and they should permit a maximum exposure of the materials. Trays of the type most often seen have a spreading surface formed either of wire screen or wooden slats held firmly in a narrow but rigid wooden or metal frame. Many of the trays now in use have been employed in sun or other drying. If new trays are made, the one-man tray, about 2½ to 3 feet square, will be found to be the most convenient.

Wooden-slat trays can be more cheaply constructed than wire-screen trays, but they have a high rate of upkeep. These trays, however, are not affected by sulfur fumes or fruit acids, for which reason they are preferred for most fruits.

Conveying the Trayed Material

The trucks for conveying loaded trays are of two general types. In one a skeleton frame is provided with cleats, upon which the trays rest. The cleats are from 2 to 4 inches from center to center above one another. These trucks are made of various combinations of wood or angle iron. The other, which may be called the stack type, has a low floor supported by wheels 3 to 5 inches in diameter. The trays are piled or stacked one above the other, and the desired space between them is maintained by the raised sides of the trays. Various alterations may be made for convenience in handling and loading.

PRETREATMENT

The original method of preparing fruits and vegetables for drying consisted in washing, peeling when desirable, cutting, and traying. By this method most dark-colored materials made fairly presentable dried foods, but light-colored fruits and vegetables did not. The attempt to overcome this difficulty led to the introduction of blanching, or processing, and sulfuring.

Blanching, or Processing

The blanching, or processing, agent is usually steam or hot water, which helps the product to retain its natural color. In the steam treatment the material is subjected to live steam for the required period. In blanching by hot water, the temperature is maintained at 190° F. to the boiling point, depending on the material being treated. As a rule, steam blanching is preferred to blanching in liquid, because the loss of soluble constituents of the food is less, a better flavored product results, and the use of steam is ordinarily more convenient.

Sulfuring

Light-colored fruits (apricots, peaches, pears, and at times grapes and figs) are sulfured in order to prevent discoloration during and after drying and to facilitate drying. Sulfuring plasmolyzes the cells and makes permeable the semipermeable cell membrane, thus facilitating the diffusion of water from the interior to the surface.

When the general plan of operation makes it desirable, the fruit on trays is sulfured in an enclosed chamber, provided with an entrance for the sulfur gas and an exit for a draft. The chamber is usually large enough to hold one to two loaded trucks. Preferably the sulfur is burned in shallow pans stacked one above the other in zigzag formation. This method gives a large quantity of sulfur dioxide in a comparatively short time. Sometimes a sulfur stove is placed outside the chamber and the sulfur fumes are carried into the chamber by flues. Sulfuring should always be as light as possible to accomplish the desired results.

DRYING

Types of Driers

The type of equipment best adapted to any particular use depends upon several factors. If the products are to be dried for home or farm use, then the equipment should be as simple as possible. Such equipment and suitable methods are described in Farmers' Bulletin 984 (*3*).

If the dried material is to be prepared in large quantities for sale to the public, then the type of equipment will depend to a great extent upon the nature of the product desired. To meet these needs, many devices have been originated and patented, so that all phases of drying are well covered.[4]

VACUUM DRIERS

Materials can be dried more rapidly and at lower temperatures in vacuum than at atmospheric pressure. Such foods as are extremely susceptible to damage by heat are more safely dried in vacuum.

However, vacuum driers are seldom used in large-scale operations on the usual commercial grades of dehydrated fruits and vegetables. The apparatus is too expensive and usually the advantages gained

[4] See list of United States Patents, p. 37.

are not sufficient to compensate for the added cost of equipment and operation. Enzymes are not inactivated by evaporation alone, and it will be found desirable in many cases to inactivate them by blanching or by other means, if vacuum drying is used.

NATURAL-DRAFT DRIERS

Natural-draft driers depend for their circulation upon the expansion of air when heated and its consequent uplift by adjacent cooler and denser air. Such driers cost less to build than forced-draft driers, but their operation is less efficient and more expensive. It is difficult to obtain satisfactory drying conditions within them, and a long drying period is required. Recirculation is rarely practical with natural draft; consequently heat is wasted unnecessarily in the discharged air.

FORCED-DRAFT DRIERS

The greater efficiency and economy of forced draft combined with recirculation has been clearly demonstrated by the Bureau of Agricultural Chemistry and Engineering (*12*) and the Oregon Agricultural College (*19*, *20*). As a result, many operators of tunnel driers have substituted forced draft and recirculation for the natural draft previously used.

The essential characteristics of all ordinary forced-draft driers are: (1) A single or multiple-unit drying chamber; (2) an air-heating unit; (3) a power-driven fan; (4) an air duct for conveying heated air from the heater to the drying chamber; and (5) a dampered recirculation duct for returning any part or all of the used air from the drying chamber to the heater.

CONVEYOR-BELT DRIERS

In driers of the conveyer or endless-belt type, the material is carried through a drying hood or chamber on one or more moving endless belts made of slats or wire mesh. These driers are used successfully in completing the drying of partially dried raisins and in drying sweet corn (*10*). This method is not suited to fruits that stick to the belt or to fruits likely to be injured by dropping from one belt to another when multiple-staggered belts are used. Neither are such driers adapted to irregular or discontinuous loading and drying operations. Because of these limitations and their small loading capacity, conveyer-belt driers are less practical than tunnel and compartment driers for general use.

COMPARTMENT DRIERS

Compartment driers (*4*, *5*, *12*) have a drying chamber divided by partitions into several compartments, each holding one or two stacks of trays. These trays can be handled most conveniently on trucks. Air is carried from the heaters through a main duct, from which portions are diverted to each compartment. Circulation in a vertical direction through the tier necessitates a shifting of the trays during drying, inasmuch as the contents of the trays farthest from the source of the air supply dry more slowly than the material on nearby trays. For this reason circulation of the air across the trays is preferable. The air is discharged from each compartment into a recirculation duct, to be either reheated or discharged from the drier without passing through any other compartment. (See fig. 1, p. 13.)

TUNNEL DRIERS

In tunnel driers the drying is done in a long chamber or tunnel, in which both the materials and the air move horizontally for the most part (*6*, *16*). A concrete-slab floor- hollow-tile walls, and a reinforced-concrete ceiling make a durable and fireproof drier. Many driers, however, have wooden floors and double walls and ceilings of tongue-and-groove flooring nailed to a skeleton framework of 2 by 4's. Although the dimensions and capacities of the tunnels vary, a typical tunnel is about 40 feet long, 6 feet wide, and 6 feet high and is capable of holding a single line of 10 trucks, each truck carrying a double stack of trays 2½ feet square. Handling the trays on trucks is more economical than conveying them through the tunnel on slides. The trucks and trays should fit snugly in the tunnel, so that all the air will pass between and across the trays.

The loaded trucks are introduced through a door at one end of the tunnel, and the trucks of dried product are removed through a similar door at the other end. Air locks may be built around these doors to conserve heat during loading and unloading. The doors may be in the side wall at each end of the tunnel, with the air ducts connected at the ends, or vice versa. Flexible movement of trucks is facilitated by transfer trucks, turntables, or pivoted truck wheels.

The course of the air through the tunnel is usually opposite to that of the material to be dried, sometimes called the counter-current system of circulation. Some operators advocate circulating the air in the same direction as the material, in what may be called the concurrent system. Tunnels wide enough to hold several parallel lines of trucks have been built. In these the air is usually circulated across from one side to the other. Screens or vanes are sometimes installed in tunnels at connecting points between air ducts and the drying chamber, so that inequalities in air distribution may be corrected.

ROTARY, OR DRUM, DRIERS

There are two types of rotary driers; in one the dry material is within a revolving drum; in the other it is on the outer surface. The first type is usually direct-fired, the hot gases from the oil or gas furnaces being carried either directly through the revolving cylinder or between it and an outer shell. The food to be dried is fed into one end of the cylinder and is tumbled about as the apparatus revolves, until it is gradually delivered at the other end by a system of spiral flanges. The material must be sufficiently dry at the intake to prevent sticking to the hot surface of the drier, and the temperature within must be carefully regulated in order to prevent scorching. The second type differs from the other in that the material is deposited on the outer surface of the drum in a thin film which dries in somewhat less time than it takes the drum to make one revolution. The drums are heated from within by steam. The film of liquid or semisolid material is either deposited on the revolving drum by a feeding device or is picked up as the drum revolves with its lower surface

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in contact with the material in a reservoir beneath it. The dried material either flakes off or is removed by a scraper (*11*).

SPRAY DRIERS

For spray drying, the material to be dried must be in solution or in a state of very fine subdivision. Two types of spraying devices are common. The first forms the spray by forcing the liquid through a nozzle at high velocity. The aperture of these nozzles may be varied to increase or decrease the size of the particles of mist, or two nozzles may be opposed to increase the fogging.

The second type makes use of a rapidly revolving disk upon which the material is dropped. The centrifugal force throws it from the disk as a fine mist. This type, having no nozzles, does not require the material to be in so fine a state of subdivision as where nozzles are used.

In both types, the spray is thrown into currents of warm air passing through a vertical drying compartment. The air current is usually blown into the compartment so as to create a swirling effect, and thus maintain the spray in suspension and free from the sides until it has become solid. It then falls to the lower part of the apparatus where it collects in an unheated compartment. Spray driers are usually supplied with a dust catcher where the air leaves the drying compartment; otherwise a part of the dried material would be lost.

Juices and pulps may be dried in this type of drier. Owing to their high content of hygroscopic sugars, it is necessary to mix many of them with dextrin or other material in order to insure a satisfactory and more or less permanent powder.

HEAT

Heat plays an important part in the evaporation of moisture, first, in supplying the sensible heat needed to bring the temperature of the water to the point to which the material is raised during drying, and next, in furnishing the latent heat of evaporation, or the heat required to convert water into vapor at the temperature level reached by the drying material. The sum of the sensible heat and the latent heat of evaporation is called the total heat of evaporation. Heat also facilitates the transmission of water through the cell walls, thereby assisting its passage from the interior to the surface of the material; it increases the vapor pressure of water, thus increasing its tendency to evaporate; and it increases the water-vapor-carrying capacity of the air.

In the United States, the unit of heat customarily used is the British thermal unit (B.t.u.), which for practical purposes is defined as the heat required to raise the temperature of a pound of water 1° F.

Heat is commonly produced through the combustion of oil, coal, wood, or gas. Heating by electricity is seldom practicable because of its greater cost; but where cheap rates prevail, it is one of the safest and most efficient, convenient, and easily regulated methods. The average numbers of heat units (B. t. u.) furnished by electricity and various fuels are given in table 3. With the exception of those for electricity, these average values will vary with the origin and character of the fuel.

TABLE 3.—*Heat units furnished by various fuels and electricity*

Source of heat	Heat units furnished	Fuel required to furnish 750,000 B.t.u.
	B.t.u. per pound	*Pounds*
Fuel oil	18, 500	40
Coal	12, 500	60
Wood (air-dried, 10.3-percent moisture)	7, 589	100
Gas	[1] 750	[2] 1, 000
Electricity	[3] 3, 415	[4] 220

[1] Per cubic foot.
[2] Cubic feet.
[3] Per kilowatt-hour.
[4] Kilowatt-hours.

Direct heat, direct radiation, and indirect radiation are the types of heat generally employed in heating drying air.

Direct-heating systems have the highest fuel or thermal efficiency. The mixture of fuel gases and air in the combustion chamber passes directly into the air used for drying. This method requires the use of special burners and a fuel, such as distillate or gas, which burns rapidly and completely, without producing soot or noxious fumes. The heater consists simply of a bare, open firebox, equipped with one or more burners, an emergency flue to discharge the smoke incidental to lighting, and a main flue, through which the gases of combustion are discharged into the air duct leading to the drying chamber.

Direct-radiation systems also are relatively simple and inexpensive and have a fairly high thermal efficiency. A typical installation consists of a brick combustion chamber with multiple flues, which carry the hot gases of combustion back and forth across the air-heating chamber and out to a stack. The air is circulated over these flues and heated by radiation from them. The flues are made of light cast iron or sheet iron. The air-heating chamber should be constructed of fireproof materials. The efficiency of the installation depends upon proper provision for radiation. This is attained by using flues of such length and diameter that the stack temperatures will be as low as is consistent with adequate draft.

Heating the air by boiler and steam coils or radiators is an indirect-radiation system, as the heat is transferred from the fuel to the air through the intermediate agency of steam. Such a system costs more to install and has a lower thermal efficiency than either of the other two systems. It is principally adapted to large plants operating over a comparatively long season on a variety of materials where the steam is needed to run auxiliary machinery or to process vegetables.

AIR

Large volumes of air are required to carry to the products the heat needed for evaporation and to carry away the evaporated moisture. Insufficient air circulation is one of the main causes of failure in many dehydrators, and a lack of uniformity in the air flow results in uneven and inefficient drying.

FANS

The fan may be installed to draw the air from the heaters and blow it through the drying chamber, or it may be placed in the return-air duct to exhaust the air from the chamber. An advantage of the first installation is that the air from the heaters is thoroughly mixed before it enters the drying chamber. It has been claimed that exhausting the air from the chamber increases the rate of drying by reducing the pressure, but the difference is imperceptible in practice. Either location for the fan is satisfactory, and the chief consideration in any installation should be convenience.

AIR DUCTS

Close contact between the air and the heaters and between the air and the material is necessary for efficient transfer of heat to the air and from the air to the material, and to carry away the moisture. The increased pressure or resistance against which the fan must operate because of such contact is unavoidable and must be provided for, but at other points in the system every effort should be made to reduce friction. To this end air passages should be large, free from constrictions, and as short and straight as possible. Turns in direction should be on curves of such diameter as will allow the air to be diverted with the least friction. The general rule in handling air is that a curved duct should have an inside radius equal to three times its diameter.

Moisture in the Air

The water vapor present in air at ordinary pressures is most conveniently expressed in terms of percentage of relative humidity. Relative humidity is the ratio of the weight of water vapor actually present in a space to the weight the same space at the same temperature would hold if it were saturated. Since the weight of water vapor present at saturation for all temperatures here used is known, the actual weight present under different degrees of partial saturation is readily calculated from the relative humidity.

Relative humidity is determined by means of two thermometers, one having its bulb dry and the other having its bulb closely covered by a silk or muslin gauze kept moist by distilled water. Tap water should not be used because the mineral deposits from it clog the wick, retard evaporation, and produce inaccurate readings. The wick must be kept clean and free from dirt and impurities. The two thermometers are either whirled rapidly in a sling or used as a hygrometer mounted on a panel with the wick dipping in a tube of water and the bulbs exposed to a rapid and direct current of air. The relative humidities corresponding to different wet- and dry-bulb temperatures are ascertained from charts furnished by the instrument makers, or published in engineers' handbooks.

Relation of Drying Conditions to Drying Rate and Quality of Product

As a general rule, the more rapidly the products have been dried, the better their quality, provided that the drying temperatures used have not injured them. Some fruits and vegetables are more susceptible to heat injury than others, but all are injured by even short exposures to high temperatures. The duration of the exposure at any temperature is important, since injury can be caused by prolonged exposure at comparatively moderate temperatures.

The rate of evaporation from a free water surface increases with the temperature and decreases with the increase of relative humidity of the air. The complex cellular structure and chemical nature of fruit and vegetable tissues retard evaporation so that under no conditions of temperature and humidity does the rate of evaporation from them equal that from a free water surface. When conditions are such that surface evaporation from the tissues exceeds the rate of moisture diffusion to the surface, the surface may become hard and seal in the moisture. This condition, known as case-hardening, is overcome by reducing the temperature of the air or by increasing the humidity. The maximum rate of drying, then, is attained by using the highest temperature which will not injure the product, the humidity being sufficient to prevent case-hardening. In general practice the temperature of the air entering the drying chamber should not exceed 160° to 170° F. The humidity at the air-outlet end of the drier should not greatly exceed 65 percent. In driers employing recirculation the conditions of temperature and humidity may be largely controlled by varying the recirculation.

The velocities of air flow which produce the most efficient results in the drying chamber depend upon several conditions. In general the rate of drying increases with the velocity of air movement. Low air velocities tend to bring about slow and uneven drying. Exceedingly high velocities may

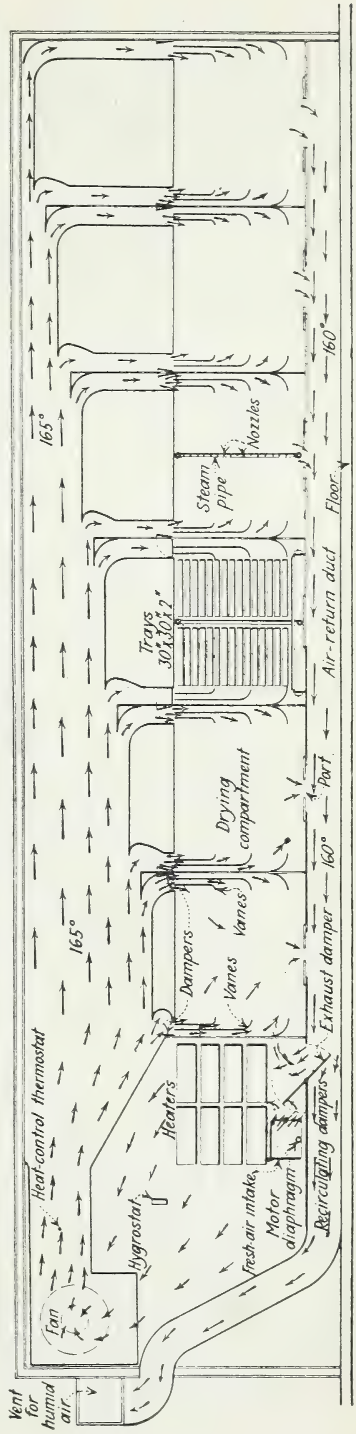

FIGURE 1.—Longitudinal section of drier, or dehydrator, of the compartment type developed as a result of research carried on by the United States Department of Agriculture in connection with the dehydration of fruits and vegetables. Air circulation is shown by arrows. (Reproduced by permission of Chemical and Metallurgical Engineering.)

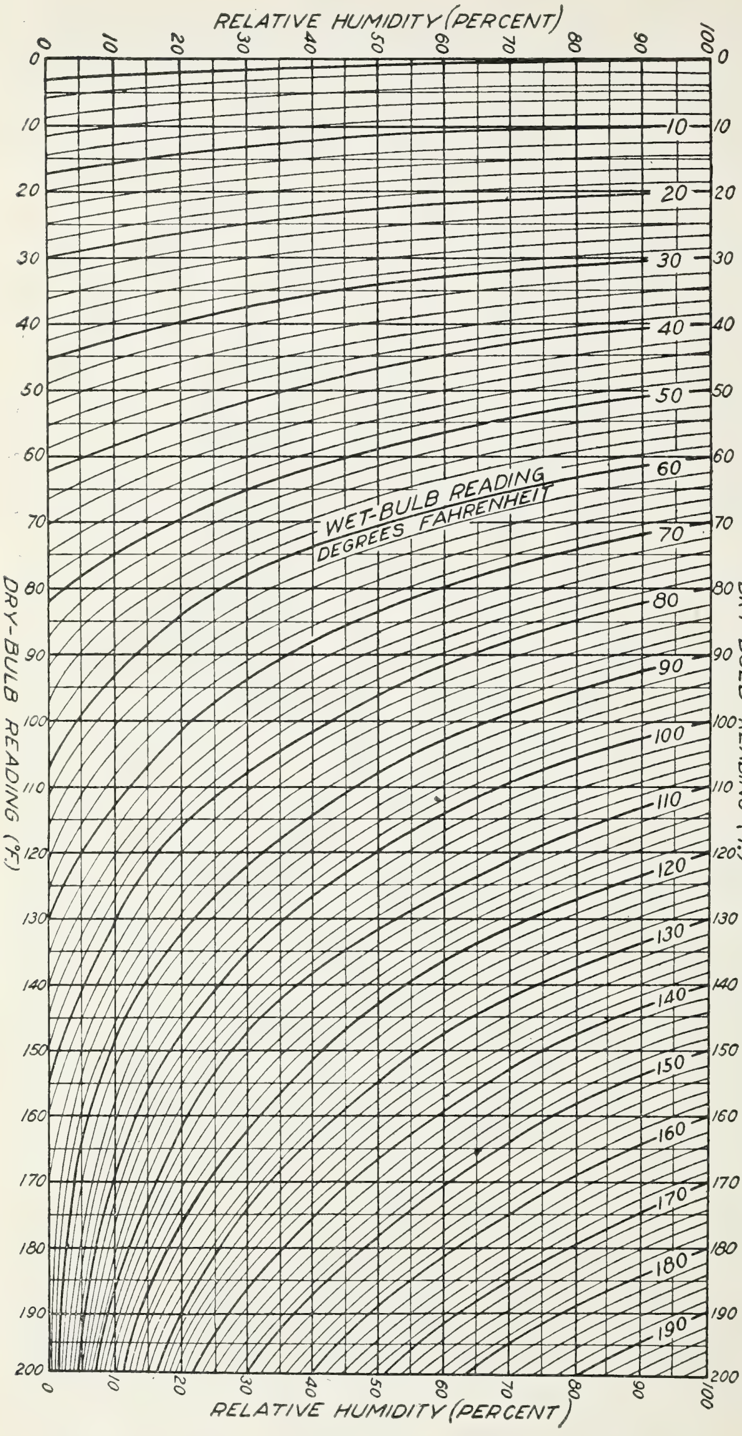

FIGURE 2.—Relative humidities corresponding to wet-and dry-bulb temperatures (based on Psychrometric Tables for Obtaining the Vapor Pressure, Relative Humidity, and Temperature of the Dew-Point U. S. Weather Bur. WB–235, 1910, by C. F. Marvin and on figure 1 in Principles of Drying Lumber at Atmospheric Pressure and Humidity Diagram, U. S. Forest Serv. Bul. 104, 1912, by Harry D. Tiemann).

not be used profitably because a point is approached at which the materials will be blown from the trays or at which the increased speed of drying will not offset the cost of operating a larger fan. Velocities of 600 to 800 feet per minute through the drying chamber are satisfactory in tunnel driers; lower velocities are permissible in compartment driers.

The most practical means of removing moisture from the air, and at the same time conserving heat, is through the steady discharge of a portion of the air leaving the drying chamber. The rest dries efficiently when mixed with fresh air from the outside and reheated. All forced-draft driers, therefore, should be provided with recirculation ducts connecting the air-outlet end of the drying chamber with the heaters and with dampers controlling the air discharged, recirculated, and drawn from the outside.

All forced-draft driers, therefore, should be provided with recirculation ducts connecting the air-outlet end of the drying chamber with the heaters and with dampers controlling the air discharged, recirculated, and drawn from the outside.

DETERMINATION OF AIR CONDITIONS

Figures 2, 3, and 4 will assist in solving recirculation problems. The curves in figure 4 are vapor-pressure curves, graduated and expressed as pounds of water vapor per pound of dry air instead of as vapor pressure. The curve corresponding to 0.020 pound of water vapor per pound of dry air, for example, represents a vapor pressure of 0.93 inch of mercury. These curves, therefore, can be used as vapor-pressure curves in problems that do not involve the actual computation of vapor pressures.

The practical application of the charts in solving various problems can best be illustrated by means of examples. The charts given here serve merely to indicate the methods of computation. In reaching exact results, the writers used larger charts than could be reproduced here, showing more subdivisions.

RELATIVE HUMIDITY FROM KNOWN WET- AND DRY-BULB READINGS

Example: Dry bulb = 150° F.; wet bulb = 100° F.

Find in figure 2 the intersection point of the lines corresponding to a dry-bulb temperature of 150° F. and a wet-bulb temperature of 100° F. The line representing the relative humidity at this point reads 18 percent.

POUNDS OF DRY AIR AND OF WATER VAPOR PER CUBIC FOOT UNDER KNOWN CONDITIONS OF TEMPERATURE AND RELATIVE HUMIDITY

Example: Dry bulb = 150° F.; relative humidity = 18 percent.

According to figure 3, air at 150° F. and 18 percent relative humidity contains 0.062 pound of dry air and 0.002 pound of water vapor per cubic foot. The weight of the mixture would then be the sum of these weights, or 0.064 pound per cubic foot.

CHANGE IN RELATIVE HUMIDITY PRODUCED BY A CHANGE IN TEMPERATURE

Example: Lowering the temperature from 150° F. and 18 percent relative humidity to 100° F.

On figure 4 start at the point corresponding to 150° F. and 18 percent relative humidity and follow parallel to the nearest curve until the 100° F. dry-bulb temperature line is reached. The relative humidity at this point reads 71 percent.

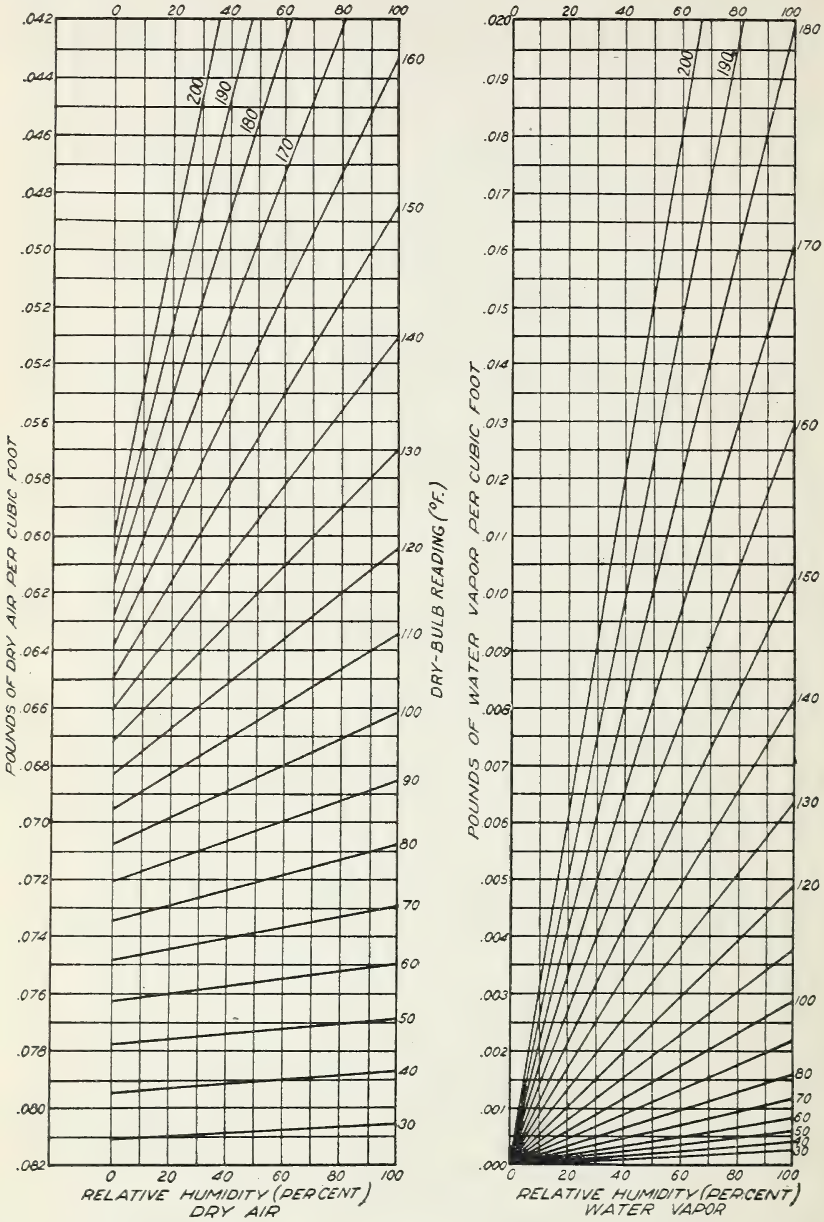

FIGURE 3.—Pounds of dry air and of water vapor per cubic foot, at a barometer reading of 29.921 (based on table 1, p. 430, v. 1, of Mechanical Equipment of Buildings, by Luis Allen Harding and Arthur Culls Willard, 1917).

Example: To find the temperature at which the air under the foregoing conditions would reach 100 percent saturation.

Follow parallel to the nearest curve as before until the 100 percent relative humidity line is reached. The temperature at this point reads 89° F.

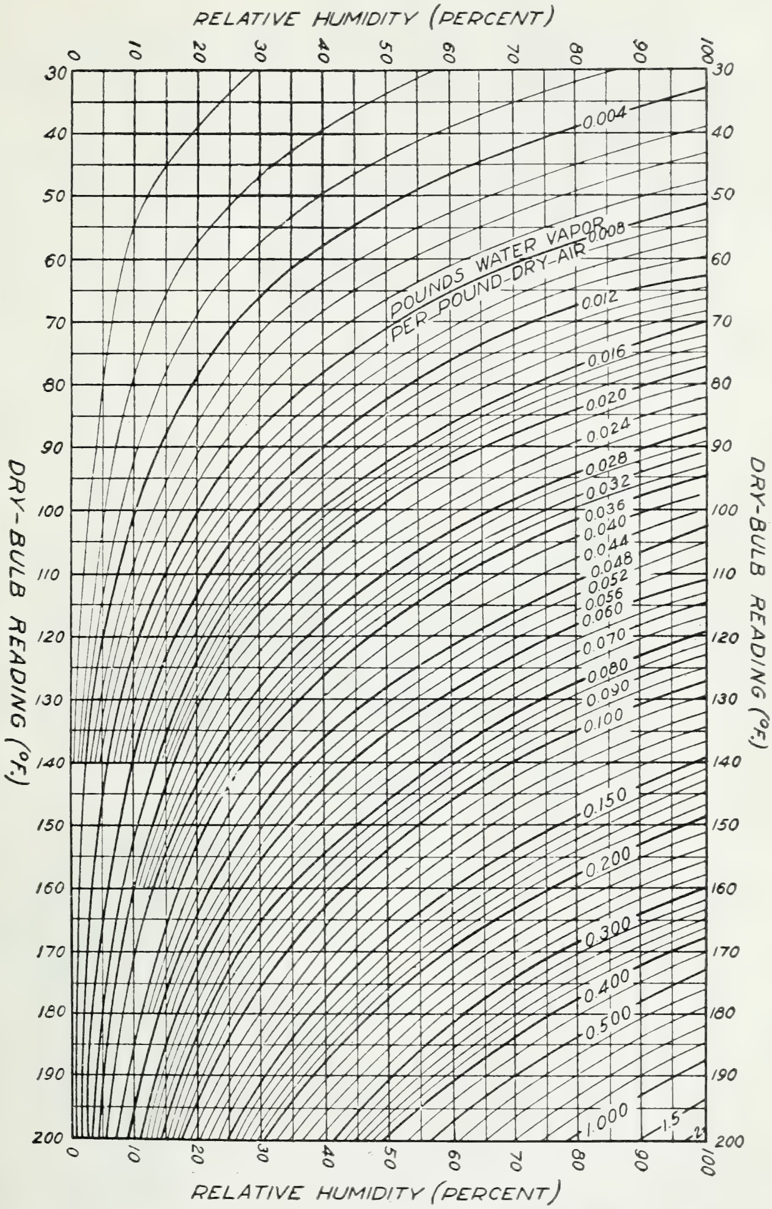

Figure 4.—Pounds of water vapor per pound of dry air.

Example: Raising the temperature from 70° F. and 50 percent relative humidity to 150° F.

Find on figure 4 the point corresponding to 70° F. and 50 percent relative humidity and follow parallel to the nearest curve to the 150° F. dry-bulb temperature line. The relative humidity at this point reads 5 percent.

CHANGE IN VOLUME PRODUCED BY CHANGE IN TEMPERATURE

Example: One cubic foot of air at 150° F., 18 percent relative humidity, would have at 100° F. a relative humidity of 71 percent, according to figure 4.

According to figure 3, air at 150° F. and 18 percent relative humidity contains 0.002 pound of water vapor and 0.062 pound of dry air, or 0.064 pound of mixture per cubic foot, while at 100° F. and 71 percent relative humidity the mixture contains 0.002 pound of water vapor and 0.068 pound of dry air and weighs 0.070 pound per cubic foot. Therefore the volume at 100° F. and 71 percent relative humidity would be $\frac{0.064}{0.070}$ or (0.914 cubic foot).

WATER EVAPORATED DURING A GIVEN CHANGE OF TEMPERATURE AND HUMIDITY

Example: Air enters the drying chamber at 160° F. and 20 percent relative humidity and leaves at 120° F. and 65 percent relative humidity.

According to figure 4, air at 160° F. and 20 percent relative humidity contains 0.044 pound of water vapor per pound of dry air, while at 120° F. and 65 percent relative humidity it contains 0.050 pound. Then there has been evaporated into the mixture $0.050-0.044$, or 0.006 pound of water vapor per pound of dry air. Since 1 cubic foot of the original mixture at 160° F. contained 0.060 pound of dry air (fig. 3) there has been evaporated 0.060×0.006, or 0.00036 pound of water per cubic foot of the original mixture at 160° F. and 20 percent relative humidity. If the air was entering the drying chamber at the rate of 1,000 cubic feet a minute, theoretically the evaporation would be 0.36 pound of water a minute.

Engineering Calculations For Designing a Tunnel Drier

The characteristics of a drier may be determined approximately by calculations based on the nature and quantities of the materials to be dried. When the drier is to be used for several materials separate computations must be made for each, so that the drier will fulfill the requirements for all. Such calculations are useful in designing a new drier and in remedying the defects of one already in operation.

To illustrate the computations involved, let it be assumed that a tunnel drier equipped for recirculation and employing the countercurrent system of air circulation is to be built with a capacity for drying 7 tons of fresh prunes daily. It will be assumed that the temperature of the outside air is 60° F. General experience in drying prunes indicates that if air is heated to 160° at about 20 percent relative humidity and has a temperature drop of 35° in passing through the tunnel and a humidity at the discharge end not exceeding 60 to 65 percent, the drying period will not exceed 25 hours, and about

35 pounds of dried prunes will be obtained from 100 pounds of fresh prunes. The tunnel drier will be designed, therefore, to embody these characteristics.

SPREADING AREA

The following equation gives the spreading surface in square feet:

$$\frac{\text{Pounds fresh product dried} \times \text{drying time (hours)}}{\text{24 hours} \times \text{pounds load per square foot of tray.}}$$

Assuming an average load of 3 pounds of fresh prunes per square foot of spreading surface, the spreading area will be $\frac{14{,}000 \times 25}{3 \times 24}$, or 4,861 square feet.

NUMBER OF CARS

If trays 3 feet square are used on trucks, each holding 2 stacks of trays 25 high, the spreading area per truck will be $3 \times 3 \times 2 \times 25$, or 450 square feet, and the nearest number of trucks furnishing 4,861 square feet of spreading surface will be 11, furnishing 4,950 square feet.

FREE CROSS-SECTIONAL AREA OF TUNNEL

If 3 inches of vertical space be allowed each tray, and 1 inch of this represents the thickness of the tray, there will be 2 inches of open vertical space per tray, or $\frac{\text{2 inches} \times \text{36 inches} \times 2 \times 25}{144}$, which is 25 square feet of free cross-sectional area, through which the air can pass, provided all spaces on all sides of the trucks are occupied by baffles. This figure (25 square feet) will be used later in calculating the air velocities through the tunnel.

QUANTITY OF WATER EVAPORATED

If the tunnel is to have a capacity for drying 7 tons, or 14,000 pounds, of prunes each 24 hours, assuming that 35 pounds of the dried product will be obtained from every 100 pounds of the fresh fruit, there will be evaporated $14{,}000 \times 0.65$, or 9,100 pounds of water each 24 hours—an average of 6.32 pounds a minute. A definite amount of heat will be required to bring about the evaporation of this quantity of water.

HEAT REQUIREMENTS FOR EVAPORATION OF WATER

The requirement for sensible heat will be 1 B. t. u. per pound of water evaporated from the material per degree increase in its temperature. The actual temperatures of the products during drying lie above the wet-bulb temperature and approach the dry-bulb temperature as the drying progresses and the rate of evaporation decreases. For safety in calculation it may be assumed that the product becomes heated to the dry-bulb temperature at the hot end of the tunnel. In the example considered, increasing the temperature of the fruit from 60° F. outside temperature to 160° in the tunnel makes the sensible heat requirement 100 B. t. u. per pound of water evaporated.

The latent heat of evaporation ranges from 1,035.6 B. t. u. at 100° F. to 977.8 B. t. u. at 200° per pound of water, but for ordinary purposes of calculation it may be considered as 1,000 B. t. u. per pound of water evaporated. The total heat of evaporation required per pound of water evaporated under the conditions assumed will be $100+1{,}000$, or 1,100 B. t. u., and for 6.32 pounds per minute it will be $6.32 \times 1{,}100$, or 6,952 B. t. u. per minute, on an average. The actual amount of heat which must be supplied by the fuel and carried by the air will have to be much larger to compensate for the heat losses in the drying system.

HEAT LOSSES

The principal ways in which heat is lost in a drying system without being used as heat of evaporation are (1) through incomplete combustion of the fuel, (2) in flue gases escaping from the stack, (3) by radiation through the walls of the system, (4) by air leakage through open seams or when doors are opened during drying operations, (5) through the removal of heated material, trays, and trucks from the drying chamber, and (6) through the necessary discharge of a portion of the air.

THERMAL EFFICIENCY

The relation between the amount of heat actually used in the evaporation of water in a drier and the total amount of heat generated by the fuel is called the thermal efficiency of the drying system. This ratio, which is expressed in percentage, is determined by dividing the number of heat units required for the total heat of evaporation by the number supplied by the fuel consumed during the same period and multiplying the result by 100. If 1,100 B. t. u. be taken as the average quantity of heat required to evaporate 1 pound of water, the thermal efficiency of the whole system can be expressed as follows: Thermal efficiency $=\frac{\text{Pounds water evaporated} \times 1{,}100 \text{ B. t. u.}}{\text{Units fuel used} \times \text{B. t. u. per unit}} \times 100.$

The thermal efficiency of the system is the product of the thermal efficiencies of the heater and drying chamber calculated separately. The thermal efficiency of the heater shows the ratio between the heat generated by the fuel and the heat received from the fuel and carried by the air to the drying chamber. The thermal efficiency of the drying chamber gives the ratio between the heat received from the fuel and carried by the air and the total heat of evaporation.

Tunnel and cabinet driers operating under conditions of partial recirculation should average better than 40- to 50-percent efficiency for the drying chamber. The thermal efficiency of the whole system will be influenced largely by the types of heaters (direct heat, direct radiation, and indirect radiation) which are selected for use in such driers. The thermal efficiencies of different heating systems in tunnel and cabinet driers shown in table 4 may be assumed. These values may be used to determine the approximate amount of heat which must be generated and the portion of generated heat which must be carried by the air in the drier being designed. In each case the lower value given is sufficiently conservative to provide a reasonable margin of safety.

TABLE 4.—*Assumed thermal efficiencies of different heating systems*

Heating system	Thermal efficiency		
	Drying chamber (tunnel or cabinet)	Heater	Whole system
	Percent	*Percent*	*Percent*
Direct heat	40–50	90–100	36–50
Direct radiation	40–50	80–90	32–45
Indirect radiation	40–50	60–70	24–35

HEAT TO BE GENERATED BY THE FUEL

If the heater selected is one of the direct-radiation type, burning ordinary fuel oil, the thermal efficiency of the whole system, according to the data in table 4, may be expected to be at least 32 percent. In other words, the total heat of evaporation will equal 32 percent of the total heat which must be generated.

$$\frac{\text{Total heat of evaporation}}{0.32} = \text{Total heat which must be generated.}$$

For the drier in question this will be $\frac{6{,}952 \text{ B. t. u. per minute}}{0.32}$, or 21,725 B. t. u. per minute, on the average. One gallon of fuel oil yields 148,000 B.t.u. Therefore the burners must consume $\frac{21{,}725 \times 60}{148{,}000}$, or 9 gallons of fuel oil per hour.

AMOUNT OF GENERATED HEAT CARRIED BY THE AIR

Since the thermal efficiency of a heater of the direct-radiation type, the one selected here, is assumed to be 80 percent, the amount of generated heat carried by the air will be the total heat generated multiplied by 0.80, or 21,725 B. t. u. per minute $\times$ 0.80, which is equivalent to 17,380 B. t. u. per minute, on the average.

AMOUNT OF HEAT GIVEN UP BY THE AIR

Heat will be absorbed from the air to meet the requirements for total heat of evaporation, which has been estimated in this case to be 6,952 B. t. u. per minute. Heat will also be lost through radiation, air leakage, and absorption in heating the material, trays, and trucks. On this account an allowance of 10 percent of the generated heat being carried by the air will be added—in this case, 17,380 $\times$ 0.10, or 1,738 B. t. u. per minute. The air in passing through the drying chamber will then be required to furnish, on an average, 6,952 + 1,738, or 8,690 B. t. u. per minute.

VOLUME OF AIR REQUIRED

The volume of air required to give up 8,690 B. t. u. of heat per minute is calculated from the specific heats of dry air and water vapor. Specific heat is the ratio between the heat required to raise (or, conversely, the heat given off by cooling) a given weight of a substance

1° F. and that required to raise the same weight of water 1°, the specific heat of water being considered as 1. At constant pressure the specific heat of dry air is 0.2375, or approximately 0.24, while the specific heat of water vapor is 0.475. One cubic foot of a mixture of dry air and water vapor under given conditions of temperature and humidity will, in dropping 1°, give a number of B. t. u. represented by the expression: (Pounds of dry air per cubic foot × specific heat dry air) + (Pounds of water vapor per cubic foot × specific heat of water vapor). The number of B. t. u. given up per cubic foot of mixture in dropping a given number of degrees Fahrenheit would be: Drop in degrees Fahrenheit × the foregoing expression. Consequently a given number of B. t. u. would be given up by the number of cubic feet of mixture represented by the fraction:

$$\frac{\text{Number of B. t. u. required}}{\text{Drop (°F.)} \times [(\text{Pounds of dry air per cubic foot} \times 0.24) + (\text{Pounds of water vapor per cubic foot} \times 0.475)]}$$

In the present problem, where an average of 8,690 B. t. u. per minute is required from air at 160° F. and 20 percent relative humidity, dropping 35° in passing through the tunnel, and where the weights of dry air and of water vapor in the air at 160° and 20 percent relative humidity are 0.0598 and 0.0026, respectively, the air required, in cubic feet per minute, is as follows:

$$\frac{8{,}690}{35\times[(0.0598\times0.24)+(0.0026\times0.475)]}=16{,}000\text{, approximately.}$$

VELOCITY OF AIR MOVEMENT

As previously estimated, the tunnel will have 25 square feet of free cross-sectional area. The velocity of movement of 16,000 cubic feet of air per minute through the tunnel therefore is $\frac{16{,}000}{25}$, or 640 feet per minute.

HUMIDITY AT AIR OUTLET END OF TUNNEL

The air entering the tunnel at 160° F. and 20 percent relative humidity contains 0.0598 pound of dry air and 0.0026 pound of water vapor per cubic foot. Into 16,000 cubic feet of this mixture is evaporated 6.32 pounds of water vapor. Thus, $\frac{6.32}{16{,}000}$, or 0.0004 pound of water vapor, would be associated with the weight of dry air and water vapor in 1 cubic foot of the original mixture. Disregarding the leakage of air into or out of the drying chamber, the air leaving the tunnel would contain 0.0026+0.0004, or 0.003 pound of water vapor, associated with 0.0598 pound of dry air, or $\frac{0.003}{0.0598}$, or 0.050 pound of water vapor per pound of dry air. Air at 125° containing 0.050 pound of water vapor per pound of dry air has 56 percent relative humidity.

Drying by Recirculation of Air

After several years of research by the United States Department of Agriculture, in which practically all types of driers and the problems connected with them were studied, a compartment-type duplex dehydrator (fig. 5) of 2 fresh tons capacity was built at Los Angeles, California, and operated on a semicommercial scale on fruits and vegetables (*12*). This apparatus and the fundamental principles involved in its design and operation (*13*) suggest improvements in drying practices with many other materials. This type of drier is especially adapted for drying vegetables and is also well suited for drying fruits.

In designing the dehydrator, cognizance was taken of the cooling effect of evaporation on a drying medium, as demonstrated by the wet bulb of the hygrometer. The development of a type of drier was undertaken in which it would be possible not only to use maximum temperatures at the time of maximum evaporation from the product being treated, but also at the same time to control temperature and humidity of the drying medium as well as its distribution.

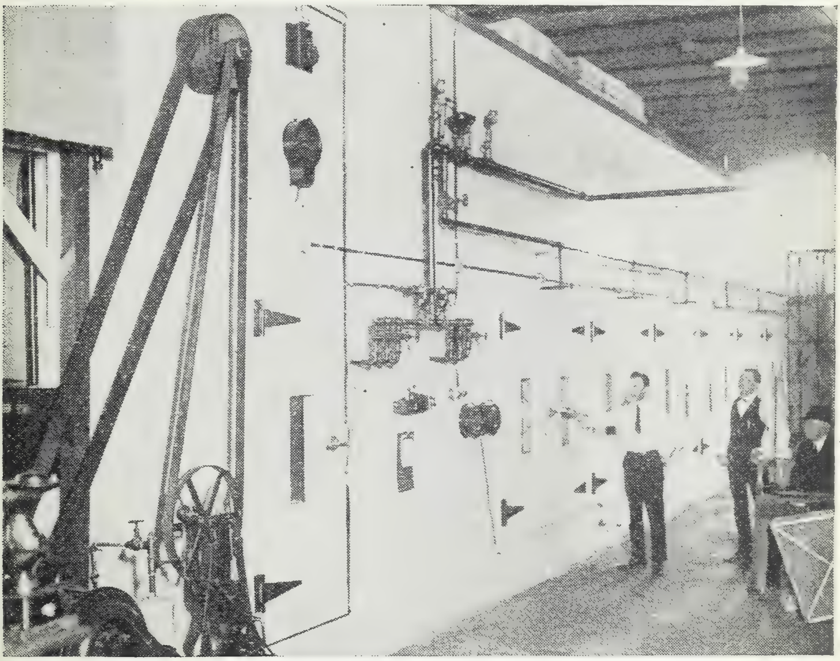

Figure 5.—A compartment-type duplex dehydrator.

Heat is not an expensive item in the total cost of dehydration. Uniformity of drying, however, is a troublesome problem and one that costs the manufacturers dear.

Proper distribution of conditioned air is perhaps the most important fundamental in drying. The flow of air over the trays should be uniform, so that drying will proceed at the same rate over the entire spreading area of the tray surface. If this condition has been met in the design of the drier, the entire charge of the product will be dried to the same degree when removed from the drier. If the product does not dry uniformly, it is in all probability because of a varying degree of maturity or size of the fruit. This indicates lack of care in grading. Uniform material should be put onto the trays of each truck, in order to secure a uniformly dried product.

Speed in drying is essential. On it depend not only the quality of the product but, of equal importance, the capacity of the drier and the day's or season's output. As the rate of evaporation is in direct proportion to the temperature, it is advisable to start the drying with a high temperature and suitable humidity, gradually reducing the temperature and humidity to the end of the drying period when the products have but little moisture left to protect them from scorching.

Tiemann (*17*) states that in drying lumber the actual temperature of the wood, while it is moist, is that of the wet bulb, provided there is sufficient circulation. In our investigations we did not find that the vegetables or fruits being dried were at the same temperature as the wet bulb. While considerable evaporation was taking place, the fruit showed a temperature that ranged about midway between the temperature of the wet bulb and the temperature of the dry bulb of the hygrometer. After evaporation had slowed down perceptibly, the temperature of the fruit began to rise, and by the end of the drying period it had closely approached the dry-bulb temperature.

The optimum drying temperature for apricots is considered to be 150° F. After 7½ hours' drying in air at 175°, it was found that the fruit had become heated to 150°. The temperature of the drying air was then cut down to 150°, and the drying was finished. An excellent dried product was obtained. The total drying time of 12 hours could no doubt have been shortened by using a greater blast of air. Similar adjustment of temperature during drying should be made for each material dried.

When blanching is necessary, as with vegetables, this operation may be done in the drying compartment. This makes use of the heat and moisture in the steam used for blanching, and the dehydrator thus serves a double purpose. In addition to economies in heat, there is a saving in labor for handling trays and trucks over that required in a factory where it is necessary to transfer them from the blancher to the drier.

The dehydrator is 60 feet long, 14 feet high, and 4 feet wide. There are six compartments, each of which accomodates one truck holding 30 trays (fig.6). Each tray is 30 inches square and 3 inches deep. This gives a total spreading area of 1,125 square feet, providing a loading capacity of 2 tons of such fruits as prunes, or about ¾ ton of ground oranges for marmalade, or ½ ton of trimmed spinach. Each compartment is a complete drying chamber independent of the others and may be used alone with all the others shut off, or it may be used in conjunction with any or all of the others. A seventh compartment houses the radiating units and the fan. Steam is used as a heating medium to warm the air. A large blower fan, motor-driven, is used to circulate the air through the drying compartments. The air leaves the fan at the rate of 18,000 cubic feet per minute and is distributed by means of a short sheet-iron duct, vanes, and sluices to the different trays, passing from the top down and horizontally across the trays, then down through a port in the bottom into a return duct, by which it is returned to the radiators and reheated the few degrees lost in one circuit.

As the air is divided among the six compartments each one gets one-sixth of the total amount, or 3,000 cubic feet. This amount is divided by a sluice that gives 1,500 cubic feet to each half of the chamber, which is further divided by the vanes on each side into three equal parts, or 500 cubic feet to five trays. Each tray being 30 inches square, takes one-fifth of the 500 cubic feet, or 100 cubic feet, which is spread over the 30-inch surface at the rate of 3⅓ cubic feet per inch per minute. This 3⅓ cubic feet of air per minute passes over a strip of the tray surface 1 inch wide by 30 inches long, coming in drying contact with only 30 square inches of material in one

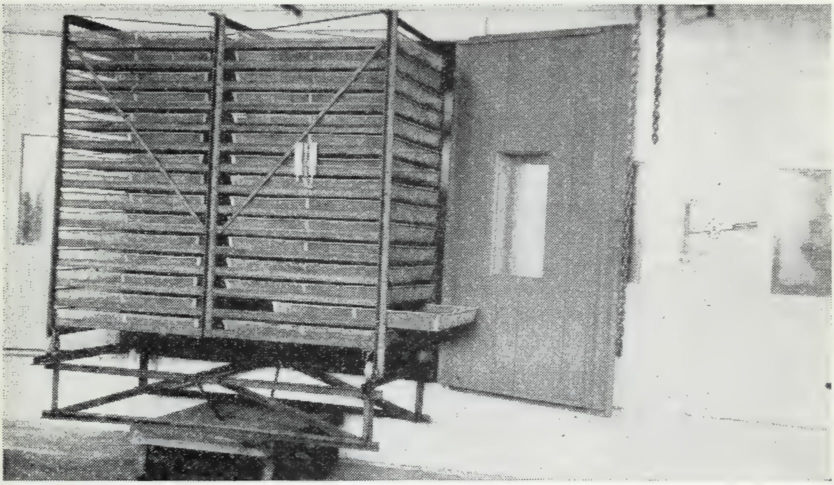

FIGURE 6.—Trays in rack on loading-platform truck, ready to be pushed into one of the drying chambers.

complete cycle. Thus use is made of a fundamental principle of heating and ventilating, that it is cheaper to move air than to heat it.

Temperature control is effected by an indirect-acting duct thermostat of the intermediate or gradual-movement type. This gives a gradual motion to the valve in the steam line and holds it firmly in any intermediate position, provided that the desired temperature prevails at the thermostat. The temperature of the air is controlled by the amount of steam which passes the diaphragm valve on its way to the vento heaters. The flexible thermostatic disk is in the outlet duct leading from the fan and is filled with a low-boiling liquid. When the temperature of the air surrounding the disk in the duct leading from the fan rises, the disk expands, owing to volatilization of the liquid within, and flexes a diaphragm which opens a valve in the thermostat. This valve permits air to pass through the air line from the air-compressor storage tank to the diaphragm valve on the main steam supply line, closing it. When the temperature of the air in the duct drops, the thermostatic disk contracts, and the compression spring closes the valve in the thermostat, cutting off the supply of air from the air compressor. This opens the air-escape port and allows the compression spring in the diaphragm valve to open it so that steam may again flow into the radiators. By use of a key, adjustments may be made for any desired temperature within the operating range of the disk. The regulator is provided with three interchangeable disks good for an operating range of 110° to 135°, 135° to 160°, and 160° to 190° F., respectively. By this means the air is held at any predetermined temperature with a variation of not more than 1° plus or minus, which gives a practically constant temperature in all six of the drying compartments.

The temperature may be varied in the compartments by setting the damper in the port at the bottom of the compartment for a larger or smaller opening. This varying of the temperature is brought about by the pull of the fan on the air flowing through the opening. With a large opening more air passes through the compartment than with a smaller opening, and a higher temperature results, as the greater volume of air carries a greater number of heat units and compensates for the refrigerating effect of evaporation on the air.

The air is humidified and dehumidified by carefully regulating a set of dampers, either by hand or by an automatic device. The dehydrator is equipped with a hygrostat which regulates the amount of compressed air admitted to the damper motor. A high humidity saturates the wooden member of the hygrostat and deflates the motor diaphragm, opening the pair of dampers, one permitting the admission of fresh atmospheric air and the other permitting an equivalent amount of saturated air to exhaust to the atmosphere. When this exchange of air has reduced the amount of moisture present in the mixture to the desired percentage of relative humidity, the hygrostat passes air to the motor diaphragm, inflating it. This closes the dampers and effects complete recirculation of the air. The moisture given off by the fruit or vegetables may be the sole source of vapor for conditioning the air under this automatic control.

The action of the hygrostat is direct, so that the movement of the dampers is positive in opening and closing. Moreover, the amount of air passed by the dampers is proportioned so that the change in humidity is so gradual that any desired relation may be obtained.

One feature in which this dehydrator differs from any other is in its adaptability to the blanching operation so necessary in drying vegetables. Perforated pipes which discharge steam through small nozzles are located in each compartment. These pipes are supplied with steam by a 1-inch pipe. There is a valve to control the flow of steam to each compartment. Products to be blanched are put into the compartment, the valves at the top of the compartment are closed, and the port in the bottom is closed. Then the steam valve is opened and the steam flows through the nozzles, filling the compartments and thoroughly blanching the products. The valves at the top of the compartment and the port in the bottom are then opened, and the circulation of air promptly clears the vapor from the compartment, and drying proceeds.

In drying the spinach described by Nichols and Powers (*9*), it was first blanched in the chambers of the dehydrator by blowing steam at 12 pounds gage into the closed compartment until the temperature of the spinach on the trays reached 180° F., as indicated by a recording thermometer whose bulb was buried in the spinach. In 3 minutes more time the steam was shut off. A maximum temperature of 196° was thus reached, the ports and dampers were then opened, and in 4 hours' time the product was completely dried.

End Point of Dehydration

Dehydrated fruits and vegetables should have a uniform moisture content low enough to inhibit undesirable microbic and chemical changes within the food, and they should be free from any part of the life cycle of moths or other insects. The moisture content of dehydrated foods directly controls deterioration within the food, and the protection afforded by sulfuring or blanching will not prevent insufficiently dried products from soon becoming unfit for use. Dehydrated products having a low moisture content are not readily attacked by insects. In the long run the additional protection afforded by a low moisture content will more than make up to the producer the loss resulting from the longer drying time and greater weight shrinkage involved. To assure best keeping qualities the moisture content of fruits containing much sugar should not exceed 15 to 20 percent, while that of other fruits and vegetables should not exceed 5 to 10 percent, the preference in both cases being for the lower percentage.

The texture, or feel, of products is a guide in determining when the proper stage of dryness has been reached. At a given moisture content products usually feel softer when hot than after they have been cooled, and often they feel softer after standing until the moisture has become evenly distributed throughout the pieces than when first cooled.

A rough test for moisture in dried fruits is to take up a double handful, squeeze it tight into a ball, and release the pressure. If the fruit seems soft, mushy, or wet, and sticks together when the pressure is released, the moisture content is probably 25 percent or more. If the fruit is springy and, when the pressure is released, separates in a few seconds to form pieces of approximately the original size and shape, the moisture content is usually about 20 to 25 percent. If the fruit feels hard or horny and does not press together, falling apart promptly when the pressure is released, the moisture content is probably below 20 percent.

At the proper stage of dryness vegetables look thoroughly dry and are often hard or crisp.

The Association of Official Agricultural Chemists has published a method for the determination of moisture in dried fruits (*1*). In using methods of this type, care must be taken to select a composite sample from different parts of the lot, so that it will be representative of the lot as a whole, and directions for preparing the sample must be carefully followed in order to obtain dependable results.

CURING

Products are never uniformly dry when removed from the drier. Large pieces and pieces not as directly exposed to the currents of heated air as most of the material contain more moisture than the rest. Products should be stored in large bins until the moisture becomes evenly distributed. This period of curing will usually take several weeks. An alternative method is to place the dried product in large friction-top cans for curing, thus insuring complete protection from contamination and insect infestation. The cans may be filled to advantage with inert gas such as carbon dioxide or nitrogen.

Leafy vegetables, like spinach, must remain in the drier until the moisture content of the stems is very low. At this point the product is bulky and the leaves are brittle. For economy in packing and handling, it is desirable to reduce the bulk by compression. For this purpose the leaves are exposed to currents of cool damp air until they have reabsorbed just enough moisture to make them slightly flexible.

INSECTS ATTACKING DRIED FRUITS

Products should be packed in the final containers or stored in insectproof intermediate containers as soon as practicable after equalization of moisture content in the curing bins (*14*).

The two generally recognized methods of insect control are fumigation (*2*) and heat treatment (*7, 8*).

PACKING AND STORING

For convenience in handling and to facilitate the application of heat or fumigation, products should be packed in the room where they were cured and stored. Such a room should be strictly clean, dry, cool, and well-ventilated. The doors should fit tightly, and the windows should be covered with fine-mesh screen to exclude dust and insects. An abundance of light assists in detecting the presence of insects and in keeping the room clean.

The types of containers chosen for packing will depend largely upon the severity of the storage conditions, with particular reference to the humidity and to chances of insect infestation. An ideal container would be one which, while moderate in cost, would keep the product from absorbing moisture when exposed to the most severe conditions of storage and shipment, and would be impervious to insects. Sealed tin cans and glass jars give absolute protection against moisture absorption and insect infestation. Friction-top cans are nearly as good. Tin containers, necessary for export shipments of dehydrated foods, are more expensive than paper containers. Wooden boxes are generally used for bulk goods. Liners of heavy paper or cardboard, and sometimes additional liners of waxed paper, are used. The use of moistureproof cellophane packages is increasing.

All types of paper containers with which experiments have been made allow the absorption of moisture when the products are stored in damp places. Also paper containers do not give perfect protection against all insects, some of which can bore holes in paper, while the larval forms of others are so small that they can crawl through the slightest imperfections at the joints where the cartons are sealed. Most products, however, keep satisfactorily in double or triple moistureproof cellophane or waxed-paper bags packed in waxed, moistureproof cartons, provided the initial moisture content is low and no live insects in any form enter the package. Packing in insectproof and moistureproof packages cannot be too greatly stressed.

DETAILED DIRECTIONS FOR DRYING

Methods recommended for the preparation and drying of the principal fruits and vegetables, together with data on waste and yield, are given in table 5. More detailed directions for this work are given in the following pages.

TABLE 5.—*Details of dehydration of fruits and vegetables*

Product	Method of removing inedible portions	Yield of fresh prepared product from fresh unprepared product	Form for drying	Approximate tray load per square foot	Treatment: Type	Treatment: Time	Maximum drying temperatures	Average drying time	Dried product: Preferred moisture content	Dried product: Characteristics	Dried product: Keeping qualities [1]	Dried product: Yield from— Fresh prepared product	Dried product: Yield from— Fresh unprepared product
		Pct.		*Lbs.*		*Min.*	*°F.*	*Hrs.*	*Pct.*			*Pct.*	*Pct.*
Fruits:													
Apples	Peel, core, trim	65–75	Cubes or slices	1.5	Sulfur	15–30	140–160	6–10	10–15	Dry, springy	Good to fair	16–19	10–15
Apricots	Wash, halve, stone	90–94	Halves	2.0	do	15–25	135–155	10–20	15–20	Dry, leathery	do	17–20	15–19
Bananas	Stem, peel	52–57	Whole or slices	1.0	do	15–30	140–160	10–20	15–20	Slightly moist to sticky, limber.	do	28–31	13–18
Cherries (unpitted).	Wash, stem	97–99	Whole	1.0	None or steam	0–2	135–160	8–12	15–20	do	Excellent	25–30	24–30
Cherries, sweet (pitted).	do	77–83	do	1.0	do	0–2	135–160	8–12	15–20	do	do	24–28	18–24
Cranberries	do	100	Chopped pieces	.8	do	0–2	135–150	4–8	5–10	Dry, tough to brittle	Excellent to good.	10–14	10–14
Figs	Wash [2]	100	Whole	3.0	Boiling lye dip.[3]	1/12–1/2	135–160	10–20	15–20	Skin dry, glossy; flesh slightly moist.	Good	24–27	24–27
Grapes	Stem and seed after drying.	80–90	Subdivided clusters	3.5	do [3]	1/12–1/2	150–180	20–30	15–20	do	Excellent to good.	26–30	21–27
Loganberries	Wash [2]	100	Whole	1.2	None		140–150	10–15	10–15	Dry, but should not crumble	do	15–18	15–18
Peaches	Halve, pit, peel	85–90	Halves	2.5	Sulfur	15–30	145–155	15–24	15–20	Dry, leathery	Good to fair	17–21	14–19
Pears	Peel, halve, core	75–80	do	2.5	do	15–30	140–150	15–24	10–15	do	do	17–20	12–17
Prunes	Grade for size [2]	100	Whole	3.0	Boiling lye dip.[3]	1/6–3/4	145–160	20–30	15–20	Skin, dry; flesh slightly moist.	Excellent to good.	33–38	33–38
Raspberries (black)	Wash [2]	100	do	1.0	None		140–150	10–15	10–15	Dry, but should not crumble.	Good	16–20	16–20
Rhubarb	Trim stalks, wash	55–60	Slices	1.0	Steam	2–4	140–150	10–15	5–10	Dry, tough	do	6–9	2–7
Vegetables:													
Beans (green)	Trim, wash	87–92	3/4-inch lengths	.8	do	15–20	140–155	8–12	5–10	Dry, tough to brittle, greenish-black.	Excellent to good.	10–13	8–12
Cabbage	Trim	80–85	Slices or shreds	1.0	do	2–6	140–150	8–12	5–7	Dry; ribs tough; leaves crisp.	Good to fair	8–12	6–10
Carrots	Wash, peel, trim	77–82	Cubes, slices, or shreds.	1.5	do	4–8	150–160	8–12	5–10	Dry, tough to brittle.	Excellent to good.	11–14	8–12
Celery	Trim, wash	77–82	Slices or shreds	1.0	do	1–2	135–145	[4] 3–6 [5] 8–10	5–10	Dry; stalks tough; leaves crisp.	do	6–9	4–8
Corn	Husk, cut from cob after processing.	35–40	Whole kernels	1.7	do	15–20	150–165	5–10	5–10	Dry, brittle	do	25–28	8–12

Onions	Trim	88–93	Slices or shreds	1.2	do	½–1½	140	5–10	5–7	Dry, crisp	Good to fair	12–15	10–14
Parsnips	Wash, peel, trim	77–82	Cubes, slices, or shreds.	1.2	do	2–5	150–160	8–12	5–10	Dry, tough to brittle.	do	18–22	14–18
Peas (sugar)	Shell, clean, grade	55–60	Whole	1.0	Boiling water	1–2	140–150	8–12	5–10	Dry, hard, wrinkled	Excellent to good.	18–22	9–14
Potatoes	Wash, peel, trim	78–82	Cubes, slices, or shreds.	1.2	Steam	5–7	145–155	8–12	5–10	Dry, brittle	do	22–25	17–21
Pumpkin	Wash, stem, cut open, seed.	70–75	do	1.5	do	3–6	140–155	12–16	5–10	Dry, tough	do	7–9	4–8
Squash (Boston Marrow).	do	70–75	do	1.5	do	3–6	140–155	14–18	5–10	do	do	11–14	7–11
Spinach	Trim off roots, wash	45–55	Whole leaves	.5	do	1	180	6–10	5–7	Dry, crisp	Good to fair	7–11	3–6
Sweetpotatoes	Wash, peel, trim	75–80	Slices	1.5	do	6–8	160	5–10	5–10	Dry, brittle	Excellent to good.	32–35	24–28
Tomatoes	Wash, trim,[2] peel	70–85	do	1.2	None or steam	0–3	140–150	10–14	5–8	do	Good to fair	5–8	3–7
Turnips	Wash, peel, trim	75–80	Cubes, slices, or shreds.	1.2	Steam	2–5	145–155	8–12	5–7	Dry, tough to brittle.	do	10–12	7–10

[1] Based on quality after storage for 1 year.
[2] Operation is optional.
[3] Use 1- to 3-percent lye solution. After lye dipping, rinse fruit by momentary dip in fresh cold water.
[4] Leaves.
[5] Stalks.

FRUITS

APPLES

Firm-flesh, late-maturing varieties of apples are more suitable for dehydration than soft-flesh apples. The white-flesh varieties and those that bleach readily in the fumes of sulfur have a clean, white appearance when dehydrated, which adds to their market value. Apples of the medium and lower grades are dried in years of normal production, but when large production causes low prices for the fresh fruit, better grades are used.

Apples should be mature but not overripe. The picking and handling should be done with great care in order to minimize bruising. Bruised spots become discolored and must be removed from the fruit when uniform color is desired.

The fruit is pared and cored by machine in one operation, trimmed by hand, cut into the desired form by machine, trayed, sulfured, and dried. As apple tissue discolors rapidly upon exposure to the air, the cut fruit is covered with cold water or weak saline solution between succeeding steps of the preparation. Apples are commonly dried in the form of ring slices, pie slices, or cubes.

APRICOTS

The most desirable flavor of the apricot is not developed until the fruit is fully ripe, but in this condition it is difficult to handle. Therefore, apricots should be dehydrated just before they become so soft that they are mashed or lose their shape during preparation and drying. At this time the color is nearly uniform throughout, and the slightly astringent flavor of the less mature fruit is absent.

Apricots are never peeled before drying. The remaining processes in their preparation and drying are similar to those for peaches.

BERRIES

Loganberries and red and black raspberries are handled in the same manner. When of market ripeness and firmness, they are picked into shallow containers. As they crush easily, special precautions are necessary during all steps in their preparation and drying.

Berries are spread on drying trays and washed by light sprays of cold water, but they are not otherwise treated before drying. Only the conspicuously soft or crushed fruits that would mat and stick to the trays need be removed before drying. Pieces of stem, leaves, and undersized berries are readily removed by screening the dried product.

CHERRIES

Both sweet and sour cherries are dried. They are sorted to remove stems and imperfect fruits, thoroughly washed in tanks of cold running water or by sprays of cold water, pitted by machine or left unpitted, trayed, steam-processed, and dried. Unless it is collected and utilized in some way, much juice is lost in the pitting process.

CRANBERRIES

Ripe cranberries are washed, fed into machines that cut or chop each berry into two or three parts, trayed, steam-processed, and dried.

GRAPES

Most of the raisin grapes are sun-dried, unless drying by artificial heat is necessary to provide against losses resulting from early fall rains. A small part of the grape crop is dehydrated.

The unstemmed clusters or bunches of grapes are dipped into hot lye or soda solution, thoroughly rinsed in cold water, trayed, and dried.

Grapes stand high temperatures better than most other fruits. Temperatures up to 200° F. have been used for some varieties without visible injury to the fruit. The safer temperatures, however, are those given in table 5.

If the grapes are to be marketed in clusters, they are removed from the drier when they contain 15 to 20 percent of moisture. If they are to be stemmed, the moisture content should be reduced to 10 percent or less and the stemming begun as soon as the fruit has cooled. Under these conditions the grapes are hard, the stems are brittle and easy to remove, and the special stemming machines used in the process will not be gummed or clogged.

The seeding of grapes follows the stemming. Stemmed grapes are treated with steam or hot water, to increase their moisture content to about 20 percent, and fed into seeding machines.

The stems of grapes constitute about 14 percent by weight of fresh material before it is prepared for drying. From 24 to 27 pounds of stemmed grapes containing 10 percent of moisture are obtained from 100 pounds of fresh grapes, not including stems. If stemmed fruit containing 10 percent of moisture is processed until it contains 20 percent, the increase in weight will be about 12 pounds for every 100 pounds of the original product.

PEACHES

Yellow freestone peaches of the Muir and Lovell varieties are generally preferred, although the Elberta is dehydrated to a limited extent. The fruit should be firm, fully colored, and free from soft spots. The color of the fresh fruit should be uniform.

Peaches are graded for size and halved by being cut completely around the line of suture, and the pits are removed. The halved and pitted fruit may be peeled by any of the lye-peeling machines or left unpeeled. In either case the fruit is trayed, cup side up, in order to retain the juice that collects in the cavity, sulfured, and dried.

PEARS

The chief varieties of pears for drying are the Bartlett and the Anjou. The fruit is picked when the color is beginning to change from green to yellow and when, by merely being lifted, it is readily loosened from the branches. The pears are kept in boxes or crates under cool well-ventilated storage until firm ripe.

Pears are prepared in both the peeled and unpeeled forms. In preparing the peeled fruit, the stem is pulled out, the calyx is cut off, and the peel is removed by hand or by lye dipping. The fruit is then halved, and the core is removed by special scoops or knives. Between the operations in preparation the fruit should be kept in cold running water or cold weak saline solution to prevent darkening of the tissues. The prepared fruit is trayed, sulfured, and dried.

The degree of translucency in the dried product is controlled in the preparation by the extent of sulfuring (table 5). Sulfuring pears effectively preserves the original color and opaque condition of the fresh fruit.

PRUNES

The Agen (*Petite*) and Italian prunes are the varieties chiefly dried. Prunes should remain on the trees until they fall to the ground or until a light tapping of the branches causes them to fall. They are gathered from the orchard in shallow lug boxes holding not more than 60 pounds.

Prunes are prepared by cold-water washing, hot-lye dipping, rinsing, traying, and drying. The temperatures used for drying Italian prunes should not exceed 160° F.; Agen prunes are sometimes dried at 170 to 175°, without visible injury.

VEGETABLES

BEANS (STRING AND STRINGLESS)

The term "stringless" and "green" apply more particularly to the maturity than to the variety of beans. Many varieties are green or stringless at early maturity. In preparing string beans it is necessary to remove the ends and strings by hand, so that it is more economical to use stringless or green beans, which require less labor in trimming. The beans, culled free from tough, fibrous, or spotted material, are thoroughly washed, preferably by vigorous sprays of cold water. They are then cut across the short diameter of the pod by a special cutting machine, trayed, and steam-processed. Blanching by immersion in hot water or in a very dilute (less than half an ounce per gallon) solution of boiling soda also gives good results. The soda intensifies and preserves the bright green color of the fresh material, but it must be dilute so that a noticeable flavor will not be imparted to the product.

CABBAGE

All dead, diseased, and discolored leaves of the cabbage are trimmed off, and the head is cut into quarters, usually by hand. If the cuts are made vertically through the central core, the segments of the stalk are easily cut out of the quarters. The quartered cabbage is sliced by means of a slaw cutter or other rotary slicer, and allowed to drop into 1 percent salt solution. The trays are loaded, the material steam blanched and dried at 165° F., finishing at 140° F.

CARROTS

The best product is made from carrots of medium size and stage of maturity. Large, very mature carrots furnish a more deeply colored product, but they are likely to have a coarse texture and strong flavor. Carrots are washed before peeling, or, if large, quantities of fresh water are used during the peeling process. They are peeled in machines of either the rotary abrasive or lye-peeling type and, after hand trimming, are sliced, cubed, or shredded. There is a larger loss of material where abrasive machines are used than with lye peeling. They are then trayed, steam-processed, and dried.

CELERY

Celery is dehydrated chiefly for use in vegetable-soup mixtures, for preparing celery soup, or for grinding to a powder to be used as seasoning. The same qualities of crisp freshness that are required for celery marketed in the fresh state are required in material for dehydration. All diseased and discolored parts are trimmed out by hand, and the trimmed celery is given a thorough washing. For soup mixtures it is finely shredded, leaves and all, and spread directly on the drying trays. For other purposes the leaves, which dry more rapidly, are trimmed from the thick fleshy stalks by hand and dried separately. The leaves are shredded or dried whole. The stalks, cut by a rotary slicer into transverse slices about one-half to three-quarters of an inch long, are spread on the drying trays and steam processed. The steaming must be short, so that the flavor and aroma will not be dissipated.

CORN (SWEET)

All of the varieties of corn which are suitable for table use make excellent dried products. Corn to be dried is in ideal condition for harvesting during the milk stage. It is husked either by hand or by power-driven husking machines. No special attempt need be made to remove the adhering silks, as they, together with the fine particles, can be readily blown out after the corn has been dried. The corn is blanched for 10 to 15 minutes while still on the cob in order to set the milk before the kernels are removed. As young corn requires longer processing to set the milk, it is best to grade the material on the basis of maturity before blanching. The proper stage of processing has been reached when no fluid escapes from the kernels when they are cut across. The corn is then drained and cut from the cobs, either by hand slaw cutters or by power-driven corn-cutting machines, after which it is trayed and placed in the drier. Driers especially designed for drying sweet corn without using individual drying trays are in general use in the drying sections of Pennsylvania and Ohio. In driers with which trays are used, the maximum temperature of the air need not exceed 150° to 165° F., under which conditions the corn will be sufficiently dry in 5 to 10 hours. Temperatures as high as 170° can be used with safety if such temperatures prevail only during the first part of the drying. The freshly dried corn is fanned to remove all pieces of silk or cob and fine pieces of kernel.

ONIONS

The outer discolored layers are removed by hand, and the onions are sliced in a rotary slicer. Some varieties are discolored by blanching. Only a light steam blanch should ever be used. Commercial dehydrators dry onions at 140° F. Notwithstanding contrary opinion, the pungency is not lessened by higher temperatures.

PARSNIPS

After being graded for size, parsnips are peeled and washed in a rotary abrasive peeler. Hand trimming, cutting, traying, and steam blanching complete their preparation for dehydration.

PEAS (GREEN OR SUGAR)

Peas are gathered when of full size but still green and tender and before the pods have begun to turn yellow. After vining, shelling, cleaning, and grading by machinery, they are water-blanched, the processing being stopped before it splits the skins. They are then trayed for drying.

POTATOES

It is not profitable to use any grades of potatoes lower than No. 2, because of the great waste and extra labor in preparation. After being roughly graded for size, the potatoes are peeled and washed in a rotary abrasive peeler. As they darken rapidly in the air after the skins are removed, potatoes are handled rapidly and kept covered with cold running water between the steps of preparation. They must be hand trimmed before being fed through the cutting machine. On leaving the cutters, the pieces are covered with loose starch grains, which, if allowed to remain, will ruin the appearance of the product during drying and storage. The starch is most effectively removed immediately after cutting and traying by passing the loaded trays on a conveyor belt through a hood, in which they are copiously sprayed on both upper and lower sides by jets of cold water. This should be immediately followed by steam processing, which should be stopped when the pieces have been heated through to the centers but before they become mealy.

PUMPKIN AND SQUASH

Pumpkin and squash receive identical treatment. The firmer-fleshed, deep-colored varieties give a larger yield, with a more attractive color and fuller flavor. The necessity and difficulty of removing the skin makes it impracticable to dehydrate such varieties as the Hubbard. The gourds are stemmed, washed well, to remove adhering dirt, and cut into large pieces by hand. The seeds, which contain oils that may become rancid during storage of the dehydrated product, must then be completely removed. The pith should also be discarded. For general purposes, pumpkins are best cubed, although, if they are ultimately to be ground to flour, they may be sliced or shredded. To make the most attractive cubed product, the skin should first be completely removed. This, of course, is unnecessary if the end product is to be flour. The steam processing should heat to the center and slightly soften the pieces; but, if continued too long, it will make the product undesirably sticky. Flour is made by grinding the dehydrated product.

SPINACH

Very young spinach does not dehydrate as well as that which is fairly well grown, but it should be harvested while still tender and crisp, not fibrous. The roots and coarse stems are cut from the leaves, and the inferior leaves are sorted out. Spinach requires thorough washing to free it entirely from dirt. The steam processing following traying should be stopped before the leaves begin to soften, collapse, and mat on the trays. High-temperature drying (200° F.) will shorten the drying time and retain Vitamin C to a greater degree than where low temperature (140° F.) and longer drying times are used.

SWEETPOTATOES

Sweetpotatoes can be dehydrated, and will produce an acceptable food. They are peeled by abrasive machines, sliced in ½″ pieces, and steam blanched for 10 to 20 minutes. Temperatures as high as 160° F. can be used at the start, 140° at finish.

TOMATOES

Although dehydrated tomatoes have great possibilities for use in ketchups, purees, and soups, as well as in the stewed form, their commercial production has not been extensive. Only firm, fully colored tomatoes should be used. The Stone is a satisfactory variety.

Tomatoes to be dried first receive a thorough washing with sprays of cold water. If they are to be used in the stewed form, they should be dipped in boiling water or subjected to jets of live steam for a few seconds to loosen the skin, chilled in cold water, and peeled by hand, when the stem cores are removed. To slice the trimmed tomatoes for dehydration without excessively bruising and breaking them requires the use of a slicing machine with sharp and rapidly rotating knives. The tomatoes are then carefully trayed, one slice deep, and they may or may not be lightly steamed.

To insure satisfactory keeping qualities, the lack of which has been the principal reason for not producing them commercially, tomatoes must be dried to about 5-percent moisture content, when they will snap from the trays in whole slices if the trays are lightly tapped on the bottom. As the dried product is very hygroscopic, it must be packed immediately and stored in friction-top or sealed tin cans until wanted for immediate use. The slices must be brittle in order to be readily ground, and the ground product must be stored in tin to avoid caking.

TURNIPS

Turnips are prepared for dehydration by the methods and with the equipment used for carrots. They are sliced or cubed for general purposes, or they may be shredded for soup mixtures. They should be steam-processed.

VEGETABLE-SOUP MIXTURES

The individual vegetables making up soup mixtures are dried separately and mixed together in the proper portions after drying. The formula may be varied somewhat, but potatoes usually comprise about 40 to 60 percent of the mixture. Carrots, parsnips, tomatoes, turnips, and cabbage are mixed in moderate quantity with a little celery, onion, and spinach or parsley.

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1,926,215, September 12, 1933, F. C. Stoll and C. W. Jones; machine for dehydrating pomace. [Heated tunnel and tray apparatus.]
1,927,396, September 19, 1933, B. G. Freund and C. W. Thomas—35 percent to Freund, 45 percent to Thomas and 20 percent to N. Lyons; dehydrating apparatus [for vegetables, fruits, and the like].
1,929,437, October 10, 1933, A. H. McComb—50 percent to E. R. Peacock; drying and preserving process for fruits and vegetables.
1,979,124, October 30, 1934, H. L. P. Tival; process for the preparation, in dry powdered form of aminal, fish and vegetable matter [by freezing, crushing, and adsorbing moisture].
1,988,678, January 22, 1935, G. D. Arnold; dehydrating process [for uniformly sized, comminuted material].
1,991,222, February 12, 1935, W. L. Laib; drying apparatus [for drying food products or other materials using electric fans for circulating air].
1,998,384, April 16, 1935, J. Petitpas; process for preserving fresh vegetables in the raw state. [Vacuum dehydration.]
2,000,533, May 7, 1935, R. T. Northcutt and A. L. Johnston, Jr.—to Food Concentrates, Inc.; method of producing a food powder [from fruits and fruit juices, nuts, etc.].
2,005,238, June 18, 1935, D. D. Peebles; method of manufacturing dried food products [from vegetables].
2,006,703, July 2, 1935, D. J. Van Marle—to Buffalo Foundry & Machine Co.; paste feed for driers. [Drum drier for various products, including yeast, fruit and vegetable pulps, cereals, etc.]
2,011,465, August 13, 1935, A. K. Balls and W. S. Hale—dedicated to the free use of the public; process for inhibiting the discoloration of fruits and vegetables.
2,017,728, October 15, 1935, H. E. Oskamp; dehydration apparatus [for vegetables and other foodstuffs].
2,023,247, December 3, 1935, W. B. Senseman—to Raymond Bros. Impact Pulverizer Co.; mill-drying process and apparatus [apparatus for drying and grinding materials, such as blood or fruit pulps].
2,023,536, December 10, 1935, C. C. Moore—to Vacuodri Fruit Corporation; process of drying fruit.

2,034,860, March 24, 1936, D. Dalin; drier [rotary-drum drier suitable for malt grain, vegetable, etc.].

2,037,009, April 14, 1936, W. W. Cowgill—to Sardik, Inc.; process of treating food materials. [Drum drying pulped material.]

2,040,227, May 12, 1936, F. Wernersson; apparatus for drying and heat treating material [on the recirculating principle].

2,042,145, May 26, 1936, W. A. Darrah; process of evaporating and equipment therefor [in passing article through an electric field. Includes food products.]

2,050,597, August 11, 1936, J. M. Younger—to J. M. Thorp; dehydrator [for drying trayed fruits, vegetables and the like].

2,054,441, September 15, 1936, D. D. Peebles—to Western Condensing Co.; Method and apparatus for drying liquid containing materials [such as alfalfa and fruits].

2,060,389, November 10, 1936, A. E. Wigelsworth; method and apparatus for drying organic substances [such as foods, condiments or tobacco, while preserving vitamin content].

2,074,740, March 23, 1937, F. W. Cutler and A. B. Cutler—to Food Machinery Corporation; fruit drier [for conditioning dried fruit].

2,090,984, August 24, 1937, D. D. Peebles; dehydrating apparatus and method. [Drum drier.]

2,092,776, September 14, 1937, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; fruit manipulating machine [for treating dried fruits].

2,092,777, September 14, 1937, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; dried fruit processing [for treating dried prunes and similar products].

2,094,083, September 28, 1937, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; dried fruit kneading machine and method.

2,094,084, September 28, 1937, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; dried fruit softening machine and process.

2,101,352, December 7, 1937, F. Y. Takenaga; dehydrator [for dehydrating chili peppers and similar "hollow" fruits and vegetables].

2,107,798, February 8, 1938, C. B. Pape, E. N. Thayer, and T. A. Schwarz; method and apparatus for treating dried fruits.

2,123,134, July 5, 1938, W. W. Cowgill—to Sardik, Inc.; process of treating food materials. [Drum drying in vacuum and inert gas.]

2,124,895, July 26, 1938, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; method of preparing pineapple. [Dehydrated slices.]

2,127,474, August 16, 1938, F. S. Smith; method and apparatus for [vacuum] drying.

2,128,697, August 30, 1938, J. Ettl—to Potdevin Machine Co.; drying apparatus [for articles or material passed through equalizing and drying chambers on a conveyor].

2,132,656, October 11, 1938, A. R. Smith—to Combustion Engineering Co.; flash drying control [to preserve vitamins, prevent oxidation and avoid releasing obnoxious odors].

2,132,897, October 11, 1938, J. G. W. Gentele; method of and apparatus for drying substances which contain liquids. [Vacuum drying of vegetables, berries, fish, eggs, milk, etc.]

2,134,147, October 25, 1938, J. C. Rea—to Dry Fruit Products Co.; drying apparatus [for the substantially complete desiccation of fruit and other food products].

2,137,890, November 22, 1938, E. F. Hopkins—dedicated to free use of the people of the United States; method for treatment and dehydration of fleshy plant materials [especially sweet potatoes for the manufacture of starch].

2,139,915, December 13, 1938, H. D. Rey—to The Anglo California National Bank of San Francisco, trustee; dried fruit process and product [especially whole fruit, such as plums, prunes, cherries and raisins].

2,140,788, December 20, 1938, W. W. Cowgill—to Sardik, Inc.; treatment of food materials. [Drum drying, with dried product in form of film.]

2,155,453, April 25, 1939, C. R. Stuntz; process of preparing fruit products. [Dehydrated apple pulp for reconstituting as apple sauce. May be applied to other fruits and to vegetables, such as pumpkin.]

2,156,845, May 2, 1939, J. G. W. Gentele; method of and apparatus for drying substances in vacuo. [Vegetables, berries, fish, eggs, milk, etc.]
2,172,059, September 5, 1939, F. S. Chilton; apparatus for dehydrating food products. [Sterilized and pre-heated, hydrated in tray compartments.]
2,185,129, December 26, 1939, K. Maus; process for dehydrating comminuted potatoes and root crops.
2,186,282, January 9, 1940, W. W. Cowgill—to Sardik, Inc.; apparatus for treating material. [Drum drier for fruit and vegetable products.]
2,192,041, February 27, 1940, O. Headland; method of treating and preparing vegetables [and fruits for drying and granulating].
2,215,265, September 17, 1940, E. W. Flosdorf; apparatus for the concentration and preservation of food products and biological substances [by freezing and dehydrating under vacuum while in the frozen or semi-frozen state].

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