UNITED STATES DEPARTMENT OF AGRICULTURE
Miscellaneous Publication No. 540

WASHINGTON, D. C. ISSUED June, 1944

VEGETABLE AND FRUIT DEHYDRATION

A Manual for Plant Operators

Prepared By
Bureau of Agricultural and Industrial Chemistry
Agricultural Research Administration

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 30 cents

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CONTENTS

INTRODUCTION

More than a year before the attack on Pearl Harbor military leaders and food technologists in the United States realized that technical information on the dehydration of foods might become vitally important. As a result of the war, the production of dehydrated foods has increased rapidly. Prior to the year 1941 only relatively small quantities of a few vegetables were dehydrated commercially, but at present vegetable dehydration has become a large industry. The dehydration of fruits has been a well-established and important industry for many years and considerable published information on the subject, including results of investigations by this Bureau, is available. The part of this manual dealing with fruits is not intended to be a complete guide for operators in the dehydration of fruits but presents only some of the most salient points of common information which may be of incidental interest to vegetable dehydrators. The developments in the dehydration field have been accompanied by large advances in the production of dehydrated milk, eggs, and meat.[1]

In 1940 the Bureau of Agricultural and Industrial Chemistry started new investigations on the dehydration of foods. The objectives were to discover (1) methods of decreasing the weight of foods, (2) ways of saving shipping space, (3) types of containers requiring less metal, (4) how to lengthen the storage life of dehydrated products, (5) techniques for retention of the greatest possible nutritive value of the foods.

Two dehydration training schools were conducted by the Bureau to assist the many food manufacturers who were engaged in, or about to become engaged in, the dehydration of vegetables and fruits. The first school, lasting 2 weeks, was held at the Western Regional Research Laboratory, Albany, Calif., in September 1942; and the second, lasting 2 weeks, was held in Rochester, N. Y., in October

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[1] The term "dehydration" is commonly used to denote specifically a controlled process of drying with forced circulation of heated air.

of the same year. The results of the past year's and previous research on dehydration were conveyed directly to commercial dehydrators. Lectures were given at the schools by people from the Department of Agriculture and other governmental agencies, and also by people from the Massachusetts Institute of Technology, the University of California, Oregon State College, and private industries. From these lectures and from the results of current research, a large body of information has become available.

A large number of problems have faced the new dehydration industry. The technological and engineering problems, with which this publication is concerned, are widely inclusive, ranging from the suitability of raw material to those involved in final packaging, storage, shipment, and reconstitution for use. The present publication is based on the results of both earlier and more recent work and is designed to serve as a manual for commercial operators. The detailed results of research are thus not included here; instead each division of the general subject is treated in a manner designed to facilitate application in commercial production.

LOCATING NEW PLANTS

An adequate supply, or potentially adequate supply, of suitable raw material is the primary consideration in the location of a dehydration plant, but there are really many factors involved, especially in wartime. The more important are as follows: (1) Availability of an adequate supply of suitable raw materials, (2) sufficient suitable labor for production and processing, (3) suitable fuel, (4) electric power, (5) an ample supply of pure water, (6) adequate facilities for sewage disposal and prevention of nuisance odors, (7) sanitary condition of surroundings, (8) adequate transportation facilities, (9) experienced and financially responsible management, (10) suitability of existing facilities for expansion or conversion, and (11) suitability of location with respect to war strategy. Some of these factors are self-explanatory as listed; others are discussed in the paragraphs that follow.

The conversion of tunnel-type fruit dehydrators to vegetable dehydration has been successfully accomplished in a number of cases. Other converted fruit dehydrators have proved unsatisfactory. Most fruit-dehydration facilities are not suitable for conversion to the production of "quality" dehydrated vegetables. Diversion of existing dehydrators to vegetable dehydration should be made only after a critical engineering analysis of the problems involved in conversion and the probable efficacy of the converted plant.

The problem of raw-material supply must be considered from two points of view: (1) Large production of suitable material and (2) dislocation of established economy. Large production is not sufficient justification for the establishment of a plant, since the market for fresh produce may be large enough to absorb a large part of the production. From the latter point of view, the best areas for new dehydration plants are those in which the market prices are lowest. These low prices usually result from large production and high yields, combined with relative remoteness from large consuming markets. Suitability of material is also important. Before the operator locates a plant in an area he should obtain information on the suitability of the crops for dehydration, through tests and pilot-plant operations if possible.

He may discover that a crop grown in a given area requires different treatment from that required by the same crop, and even by the same variety, grown under different conditions. He should assure himself that the crop or crops to be dehydrated are high in original nutritive and other quality factors.

Large quantities of heat, power, and pure water are required for the operation of a dehydration plant and these should be available at a reasonable price. If steam is used as a source of heat, the type of fuel is relatively unimportant. Heat consumption is lower with direct heat and this requires the use of gas or oil fuel, preferably the former.

Difficulty in disposing of wastes from the preparation line, including the wash water, has resulted in the closing of some plants. The starch from potato plant wash waters tends to settle rapidly in sewer lines and may result in clogging unless a heavy flow of water is maintained. The large tonnages of solid wastes must also be disposed of in such manner as to avoid the creation of a nuisance. Attempts have been made to recover the starch from potato plants in a salable form. The low value of the recovered crude starch makes the advisability of this process somewhat doubtful. Plants using abrasive peeling offer the best opportunity for this type of saving, because of the large peeling losses in these plants.

Plants drying onions or garlic must be located so that prevailing winds carry the nuisance odors away from populated areas. On the other hand, all dehydration plants should be located where odors from other sources will not trouble them. The flavor of dried vegetables may be damaged by absorption of such odors and the acceptability of the product seriously impaired.

PLANT LAY-OUT, EQUIPMENT, AND CAPITAL INVESTMENT

A properly planned dehydration plant is not built around a particular piece of equipment or around a certain step in the process. The different operations must be balanced, with no "bottlenecks." The capacity of each piece of equipment should therefore be somewhat flexible so that an operating balance can be obtained without seriously impairing the efficiency of any part of the plant. Plants in the capacity range of 5 to 100 tons per day, unprepared basis, are discussed here, and most of the statements are equally true for larger plants. Figures 1 to 5 illustrate floor plans that are considered later in more detail. Vegetable rather than fruit dehydration has been considered chiefly in the preparation of these plans and in the discussion of planning. Many of the general statements also apply to the dehydration of fruits.

Each prospective dehydrator will have individual preferences concerning many features of lay-out, construction, and operation. The equipment, the lay-outs, and the operating steps outlined herein are offered as constructive suggestions. Many important matters have not been illustrated because custom tailoring is necessary in almost every case. Those omitted include such operations as air desiccation, grinding, storage of raw material or finished product under special conditions, and numerous techniques still unproved on a commercial scale.

Plants much smaller than 25 tons per day are not usually in a commercially competitive position unless they have some special advantages, such as low-cost raw material or low-cost labor. Small plants,

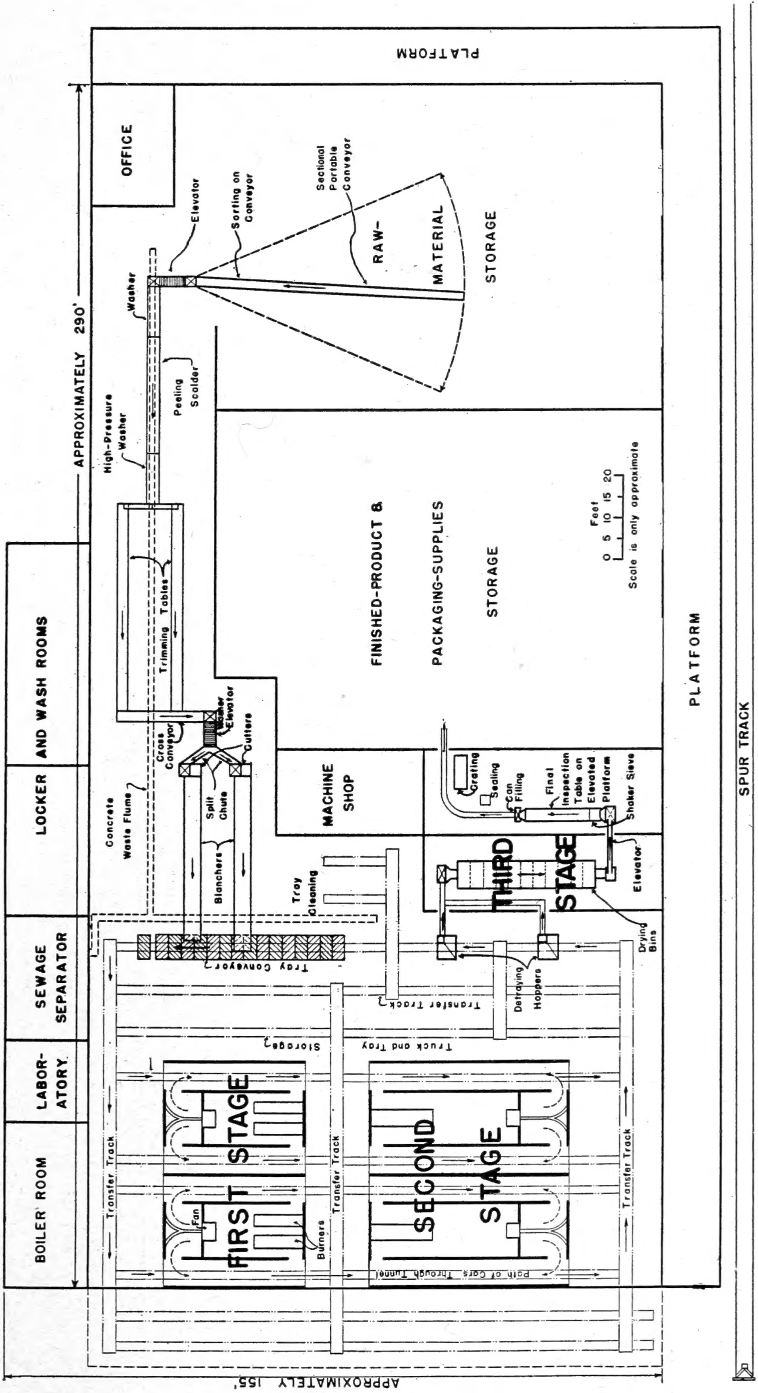

FIGURE 1.—Lay-out of 100-ton, multistage, tunnel-type dehydration plant. Floor spaces (square feet) are as follows: Raw-material storage, 8,600; finished-product and packaging-supplies storage, 8,500; preparation, 6,000; drying, 13,000; packaging, 1,000; boiler room, 800; laboratory, 400; locker and wash rooms, 1,800; office, 600; machine shop and tray repair, 700; sewerage, 600.

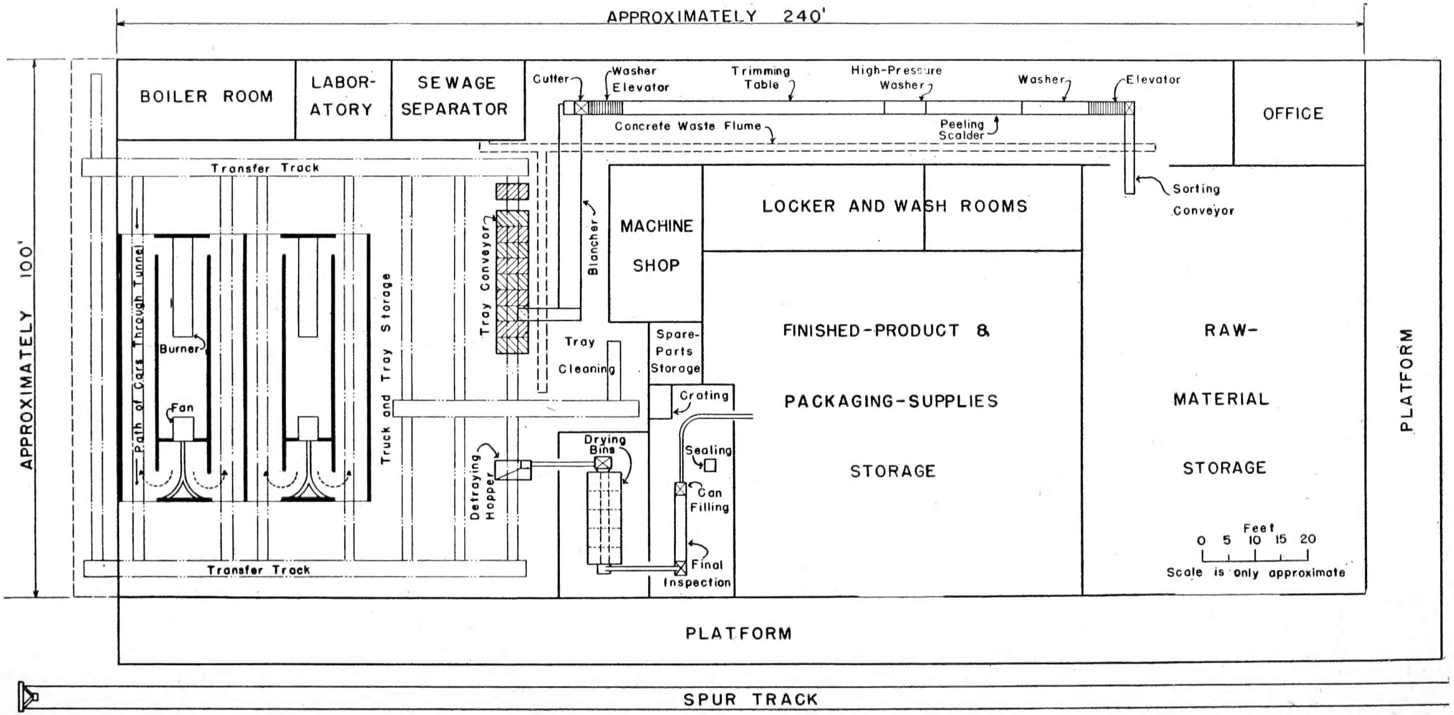

FIGURE 2.—Lay-out of 50-ton, counterflow, tunnel-type dehydration plant. Floor spaces (square feet) are as follows: Raw-material storage, 4,600; finished-product and packaging-supplies storage, 4,600; preparation, 3,200; drying, 7,800; packaging, 700; boiler room, 500; laboratory, 300; locker and wash rooms, 1,100; office, 500; machine shop and tray repair, 500; sewerage, 400.

operating as community projects or on individual farms, often justify themselves by making possible the saving of crops that have no ready market. Their value in wartime is limited by the fact that the output per unit of operating labor and construction materials is low.

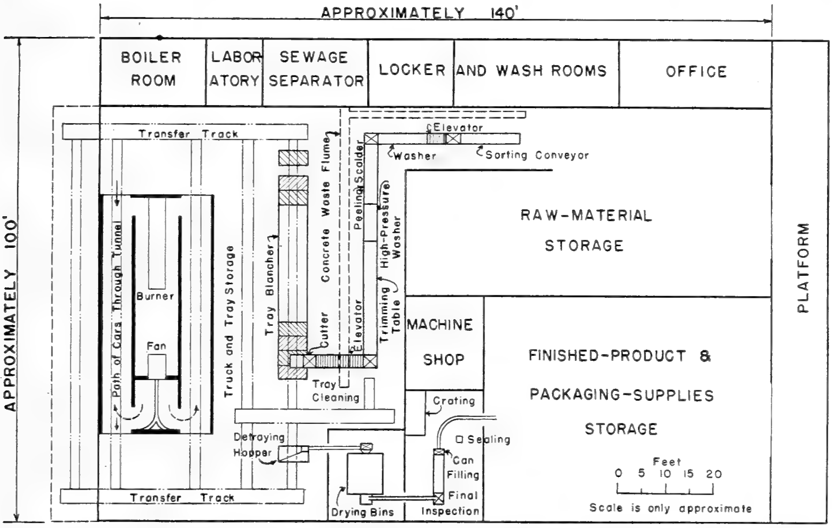

FIGURE 3.—Lay-out of 25-ton, counterflow, tunnel-type dehydration plant. Floor spaces (square feet) are as follows: Raw-material storage, 2,600; finished-product and packaging-supplies storage, 2,900; preparation, 1,800; drying, 4,000; packaging, 500; boiler room, 300; laboratory, 150; locker and wash rooms, 700; office, 450; machine shop and tray repair, 300; sewerage, 300.

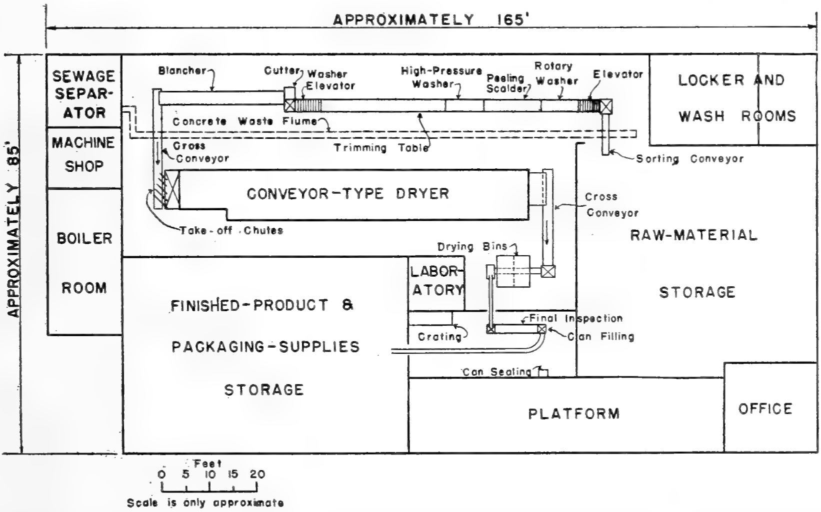

FIGURE 4.—Lay-out of 25-ton, conveyor-type dehydration plant. Floor spaces (square feet) are as follows: Raw-material storage, 2,500; finished-product and packaging-supplies storage, 2,500; preparation, 2,100; drying, 2,600; packaging, 500; boiler room, 500; laboratory, 150; locker and wash rooms, 700; office, 400; machine shop and tray repair, 200; sewerage, 250.

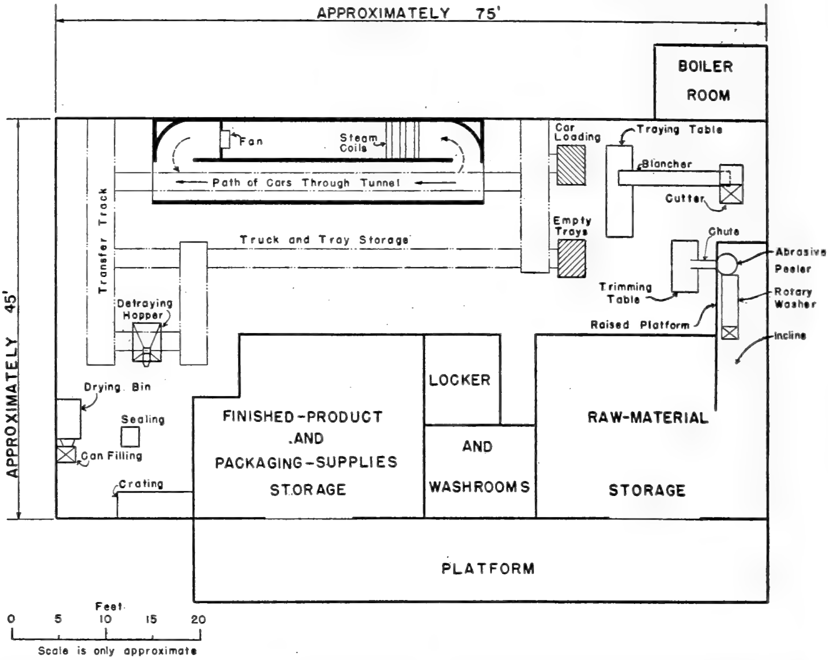

FIGURE 5.—Lay-out of 5-ton, counterflow, tunnel-type dehydration plant. Floor spaces (square feet) are as follows: Raw-material storage, 500; finished-product and packaging-supplies storage, 500; preparation, 450; drying, 1,400; packaging, 150; boiler room, 100; locker and wash rooms, 250.

Buildings and Lay-out

The building need not be expensive, but certain features are essential. It must have good concrete floors throughout and proper drainage, so that walls and floors can be washed down and kept clean. Built-in waste flumes in the floor of the preparation room are an aid in this respect. All outside openings should be screened so that flies and other insects cannot enter, and outside screen doors should have automatic closing devices. Rodentproof construction is highly desirable.

The plant lay-outs presented here show practical floor plans and will serve as guides to floor-space requirements and arrangements for the different operations. Buildings of rectangular shape are discussed because they are commonly used. If the plant is to be located in existing buildings, the lay-out must be modified to take advantage of the available space in the best manner.

In some cases it may not be feasible to locate all parts of the plant within the limits of a rectangular building. Boiler and sewage-separation rooms can be conveniently located in small adjoining buildings, or in an extension of the main building. As a safety and fire-prevention measure and to eliminate excessive temperatures within the plant, it is better to locate the boiler in a separate building. Boilers should be designed and installed in accordance with the code of the American Society of Mechanical Engineers. It may be advisable to place the office in a position overlooking the receiving and shipping platform for convenience in keeping receiving and shipping records and checking the movement of all materials in and out of the plant.

Raw-material storage must be located conveniently to the receiving platform. It should be dry, well ventilated, and cool. Refrigeration will be necessary in many cases. The size of the storage room is governed mainly by regularity of raw-material delivery. Where the plant is located close to adequate supplies and harvest is continuous, a smaller storage room is necessary than where supplies are hauled long distances or harvest is irregular.

Storage requirements vary with the product. Perhaps as much as 10 days' supply of potatoes, sweetpotatoes, and onions can be kept on hand, since these products do not deteriorate in that time, but in many cases not more than a day's supply will be necessary. Cabbage, carrots, rutabagas, and beets are usually harvested as they are needed, but since rains delay the harvest of these vegetables, many operators believe they should keep at least 10 days' supply on hand. Others say it is not advisable to keep more than 2 or 3 days' supply since these vegetables show signs of wilt after that period. One day's supply of leafy vegetables is the most that should be kept on hand unless cool storage is available. Bulk storage may be necessary if there is a shortage of sacks or boxes. This will decrease the amount of space needed but will either complicate the handling problem or necessitate special storage facilities.

The storage space for finished product and packaging supplies must be dry, cool, and insectproof and rodentproof, and should be adjacent to the packaging room and the shipping platform. The regularity of outgoing shipments is an important factor in determining the size of the finished storage room. The availability of packaging supplies is another factor to consider. Small packages of consumer goods require considerably more storage space than large packages, such as 5-gallon cans.

It is advisable to have additional storage space in adjoining buildings or on mezzanine floors to take care of unforeseen storage needs, and it may be desirable to provide clear space around the building. This space can be used for movement of trucks and additional temporary storage in emergencies. The storage space should be constructed to withstand heavy loads.

Tunnel driers require considerable floor space because of the need for transfer tracks, car tracks, car and tray storage, tray-washing equipment, and the tray conveyors used in loading. The conveyor-type drier requires relatively little floor space in addition to that occupied by the drier itself. Through circulation of air permits heavy loading on the belt, thus reducing its required size and minimizing needed floor space.

For tray-type driers, adequate storage for cars and trays must be provided. A covered platform alongside the tunnel on the outside of the building provides an inexpensive storage space. Facilities for washing or cleaning trays must be provided. Ample floor space and proper tools are necessary.

The laboratory can be conveniently located near the preparation line and the packaging room, but this is not essential. The time spent in getting a sample is only a fraction of the time spent in analyzing it. A location near the machine shop is not desirable because vibration may affect the analytical balances.

The main locker and wash rooms should be located near the preparation line since many workers are employed there. Care should be taken to avoid the movement of employees across the line of product flow.

Labor requirements are closely related to plant lay-out and equipment. For example, the length of trimming and inspection belts depends upon the number of women needed for these operations. The spacing of equipment and the flow of product are influenced by the number of workers needed for the various operations. Proper plant lay-out saves space and reduces the requirement of labor and equipment. Flow of products through the plant in a manner that eliminates cross traffic decreases the amount of labor required. Elevators and conveyors also save labor. In many instances, the use of gravity flow will decrease the required number of employees, and will eliminate elevators and conveyors at some points.

The work in the machine shop will consist mainly of repair of trays and adjustment and maintenance of preparation equipment. It should be located so as to require the least movement of the items to be repaired. Some machines are too large to take to the machine shop, and it is necessary to allow for working space alongside this equipment or provide for its removal to the outside. In many cases, equipment is shipped to the manufacturer for repairs. Storage space should be provided for spare parts and equipment and supplies.

On the basis of actual floor space in operating plants and an objective appraisal of the adequacy of these allowances, approximate floor-space requirements for various parts of the plant are given in table 1.

TABLE 1.—*Approximate floor space requirements in square feet for dehydration plants handling carrots, potatoes, and rutabagas* [1]

Item	5-ton plant [2]		25-ton plant [2]		50-ton plant [2]		100-ton plant [2]	
	Low [3]	High	Low [3]	High	Low [3]	High	Low [3]	High
Raw-material storage [4]	400	800	2,000	4,000	4,000	8,000	8,000	16,000
Finished-product and packaging-supplies storage [5]	400	800	2,000	3,500	3,000	6,000	6,000	12,000
Preparation	400	600	1,500	2,500	2,500	3,500	4,000	6,500
Drying [6]	1,000	2,000	3,500	5,000	7,000	9,000	10,000	14,000
Packaging	100	200	400	600	500	800	800	1,000
Boiler room [7]	100	200	300	500	500	800	800	1,200
Laboratory			100	200	200	400	300	500
Locker and wash rooms	200	400	500	1,000	1,000	1,500	1,500	2,500
Office			300	500	400	600	500	750
Machine shop and tray repair			200	400	400	800	500	1,000
Sewerage [8]			200	300	400	600	500	1,000
Total	2,600	5,000	11,000	18,500	19,900	32,000	32,900	56,450

[1] Because of their drying characteristics, sweetpotatoes require more tray area than allowed here and therefore have not been included. Other space requirements for sweetpotatoes are substantially the same. as those listed.

[2] Capacity given in tons per 24 hours, unprepared basis.

[3] The low limits of floor space will be undesirable in many instances.

[4] The space indicated for raw-material storage will provide from 2 to 3 days' supply of root vegetables in sacks or boxes. Additional space must be provided if a larger supply of raw material is to be kept on hand. If it is not feasible to have this storage space in one building, adjoining buildings or covered platforms may be used.

[5] Additional storage space, 50 percent or more of that indicated here, should be provided on mezzanine floors or in separate buildings for storage of chemicals, spare equipment, and other items that accumulate. It is assumed here that these dehydration plants are on a war basis and finished goods are shipped as soon as shipping facilities are available. However, for normal operation in peacetime, plants of the same capacity will ordinarily need more space for storage of finished goods.

[6] Floor-space allowances for the dehydrator are based upon truck and tray tunnel driers.

[7] Floor-space allowances for the boiler room are based upon the use of steam for blanching and incidental uses only. If steam-heated driers are used, this item must be raised.

[8] In many instances no space will need to be allocated for sewerage. Space indicated here is for settling and separation of solids from liquid wastes and for trimmings from the preparation line.

Preparation Line

Figure 6 presents the lay-out of the preparation line for the 100-ton vegetable plant. Both side elevation and floor plan are shown. The line need not be straight; it can be turned at any one of a number of convenient places as illustrated in figures 1 to 4.

Plants processing potatoes have been selected for illustration. Other vegetables, for example carrots and rutabagas, can be handled on the preparation lines illustrated with little or no change. Sweetpotatoes can be handled if lye peeling is used. The use of the lye peeler as a scalder also enables the lines to operate on tomatoes almost as outlined. Other vegetables may require considerable change in these lines. Beets are commonly cooked before peeling. Cabbage requires the use of kraut cutters and the addition of coring machines over a suitable conveyor belt; considerable rearrangement and a different type of blancher are also necessary because of the desirability of blanching on trays.

Only properly designed and carefully built machinery should be used. A poor cutter or slicer may cause damage to the product and increase washing losses. Incomplete peeling necessitates excessive trimming labor, and drastic peeling wastes the product. The cost of a good blancher and its operating costs are small compared to the loss that will be incurred by the use of one poorly designed. Improperly designed elevators, conveyors, and washers may be too rough in their action, resulting in damage to products. Some vegetables cannot be handled easily on elevators or conveyors. This is especially true of leafy vegetables. The plant should therefore be arranged to give these vegetables a minimum amount of handling.

Ruggedness of equipment and long operating life are important. High maintenance charges may soon offset any saving due to low initial investment. Repairs cause grief and expense due to interruption of production and improper handling and processing.

When there is a possibility that the stopping of any machine will interrupt the continuous flow of the product through the plant, some means of substitute operation should be available, or else there should be storage facilities for the product so that it will not deteriorate. In larger plants it may be justifiable to provide two of almost all major items of equipment. Two or even three trimming belts are preferable to one from an operating standpoint and because of the possibility of break-down. It may be desirable to provide two smaller blanchers instead of a single large one. This arrangement has particular value when two products are run simultaneously or a product is being prepared in two forms.

Oversized equipment may be a wise investment. Various parts of the preparation line are then able to handle increases in throughput which may occur as a result of improvement in quality of raw material or changes in labor and equipment. On the other hand, much can be done to reduce investment in processing equipment. The number of elevators and conveyors can be reduced by placing some machines on elevated platforms directly over other machines, thus utilizing gravity flow. This also reduces the floor space required. A properly constructed water spray over the front uncovered section of the blancher belt may satisfactorily wash the product in lieu of an expensive separate mechanical washer. In addition, a water spray

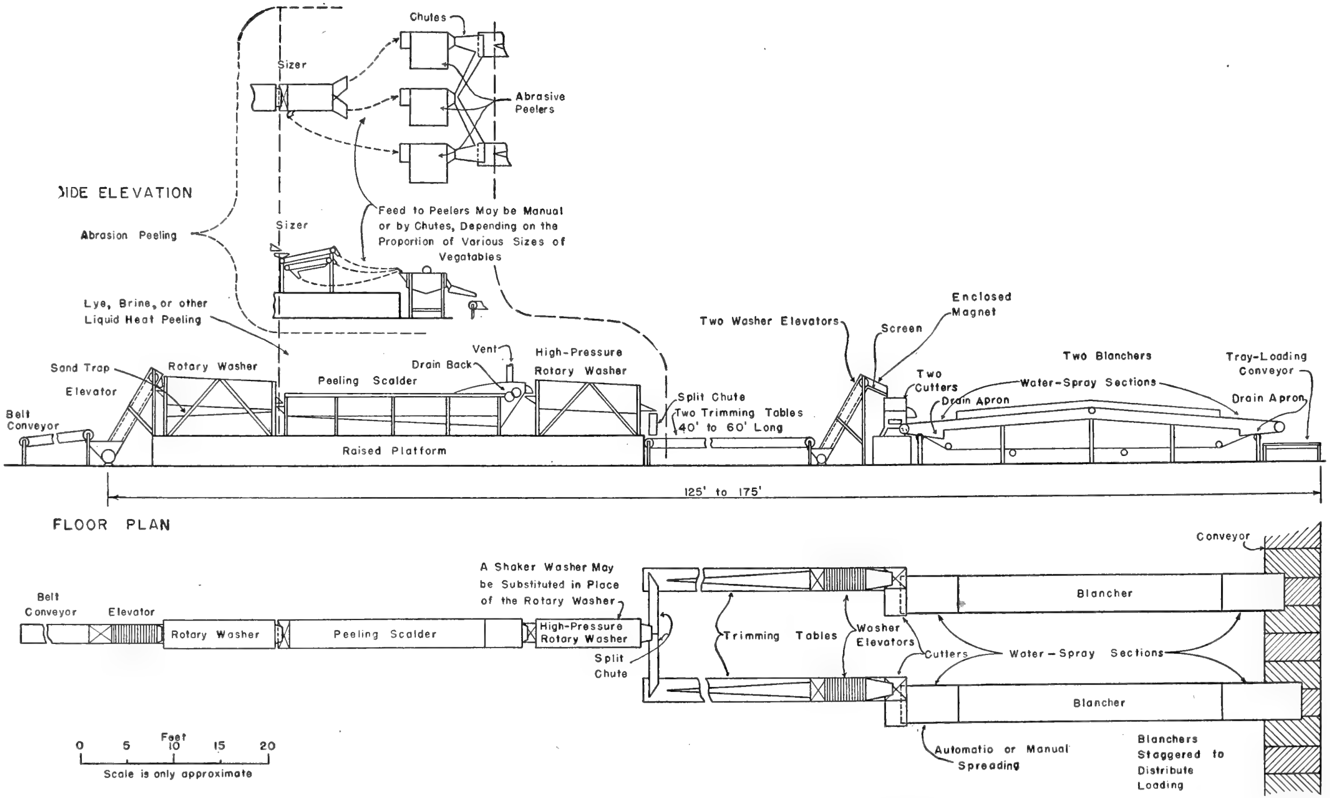

FIGURE 6.—Lay-out of preparation equipment for 100-ton dehydration plant.

at this point tends to prevent excessive humidity in the preparation room by condensing steam escaping from the front end of the blancher. Elimination of all unnecessary handling of the material reduces the amount of labor and equipment needed and results in a better finished product.

To be effective, the preparation line must be carefully laid out, with sprays at intervals to keep the product moist, and with no pockets that permit accumulation of vegetables which later contaminate the entire lot with discolored, oxidized products. Washers, either spray or rotary types, placed at intervals in the line tend to keep the product wet and clean. This is good sanitary practice.

Arrangement of floor drains beneath the preparation lines to carry off the water is necessary. This prevents accumulation of waste water and residues from the line which would soon become sour and create odors in the plant.

The best preparation line is one that continuously gets the product to the drier in the shortest time allowed by proper operating procedures. These procedures vary slightly from plant to plant and considerably with one vegetable or another.

Dehydrator

Choice of drier.—Three types of vegetable dehydrators are shown in figures 1 to 5. Figure 1 shows a plant capable of handling 100 tons of raw product per day, in continuous operation. The dehydrator is of the multistage tunnel type. Figures 2 and 3 show 50- and 25-ton plants with dehydrators of the counterflow tunnel type; and figure 4, a 25-ton plant with a conveyor-type drier. All are planned to include finishing bins.

This presentation is not meant to imply that a multistage unit is better for a 100-ton plant, and a conveyor type for a 25-ton plant. The examples are presented for illustrative purposes only and it is possible that each of these types will prove to be suitable in a wide range of plant capacities. The capacities indicated are only nominal; the true capacity of each is dependent upon the product, the drier design, heat input and air circulation, and the use of finishing bins.

In the multistage drier, the material passes first through a parallel-flow tunnel, then through a counterflow tunnel, and finally into finishing bins. If properly designed, this is a very flexible type of unit, permitting the adjustment of drying conditions to the optimum for product quality. The second-stage tunnels, used alone, are suitable for fruit drying.

The counterflow tunnels illustrated in the 50- and 25-ton plants are a conventional type. Drying times are not as short as in multistage units because the maximum temperature of the air is limited by the highest temperature that the product at the dry end can stand. The use of finishing bins, permitting removal of the product from the tunnels at a higher moisture content, partially offsets this drawback.

The conveyor type of drier shown in the 25-ton plant has shown promise in commercial operation and will doubtless be used increasingly as its operating problems are overcome.

Figure 5 shows the lay-out for a plant handling 400 pounds of potatoes per hour. If the operation is continuous, the plant will process 5 tons of raw product per 24 hours. The dehydrator is a nine-truck tunnel of small cross section, and it is assumed that one truck will be loaded every 40 minutes. The preparation line will probably be operated only one or two shifts per day; the drying will therefore continue only until all the product in the tunnel has been dried.

The operation of plants much smaller than those handling 25 tons per day is likely to be intermittent, and batch-type driers or tunnels smaller than the usual commercial type may, therefore, be preferable. The use of tunnel-type driers in a discontinuous operation is feasible only if close control of temperature and humidity is maintained during the starting-up and shutting-down periods.

The choice of drier may be influenced by the amount of labor required. If tray-type driers are used, all practical labor-saving methods and devices should be installed. Conveyor driers require less labor. Tray handling and washing may entail a considerable amount of hand labor, whereas belt cleaning may be almost entirely automatic. Where labor rates are high, the rehandling costs involved in multistage drying may be sufficient to cause a reconsideration of the system to be installed. Automatic movement of the cars in and between the tunnels may overcome this disadvantage.

The lower labor cost in operating a conveyor drier may offset the higher initial capital cost. The output per dollar of investment for a conveyor dehydrator is generally less than for a tunnel drier. It may not be possible, however, to determine which type of dehydrator is preferable on the basis of cost alone. It is probable that the choice will be determined mainly by technological factors. It may depend also upon the availability of construction materials. Availability of operating labor and materials must also be considered.

The upkeep of the drier is important. The cost of maintaining the trays in proper condition can be balanced against the upkeep of a large and costly belt or conveyor.

Ample capacity in the dehydrator is usually a good investment. Since the fuel and power costs are relatively low, an increase or decrease of even a substantial percentage does not seriously affect the total processing cost. Increased labor costs due to inefficient use of labor in the preparation line, when the dehydrator is unable to handle the output of the line, usually amounts to far more than any additional drying cost resulting from the use of a slightly oversized dehydrator.

Finishing bins used in conjunction with the dehydrator increase the capacity of the dehydrator proper by shortening the time of the main drying operation. This shortening of drying time may result in an improvement in product quality. The over-all cost per unit of drying capacity will usually be less when finishing bins are used.

Loading and stacking trays.—One tray line should ordinarily be adequate for plants handling up to 100 tons per day. Proper timing of tray loading, stacking, drying, and tray scraping is essential for efficient operation. This is especially true for large plants. A minimum of about 10 to 12 seconds should be allowed for handling each tray at the loading point, although the actual operation of taking the tray from the loading table and placing it on the truck requires somewhat less time. On this basis, the 100-ton plant is near the upper limit for one tray line. It should be borne in mind that if the rate is increased so that the handling time is less than 10 to 12 seconds per tray or if the flow of product is not uniform, two tray lines will be necessary.

Spreading the product on trays is slightly more difficult than spreading on a flat belt, because the sides of the trays are higher than the material. Leafy vegetables, such as nonblanched shredded cabbage, are an exception since this material is stacked higher than the sides of the trays. Several suggested means of spreading on trays are sketched in figure 7. The blanchers shown in figure 7, *C* and *D*, are especially well suited for uniform spreading of products.

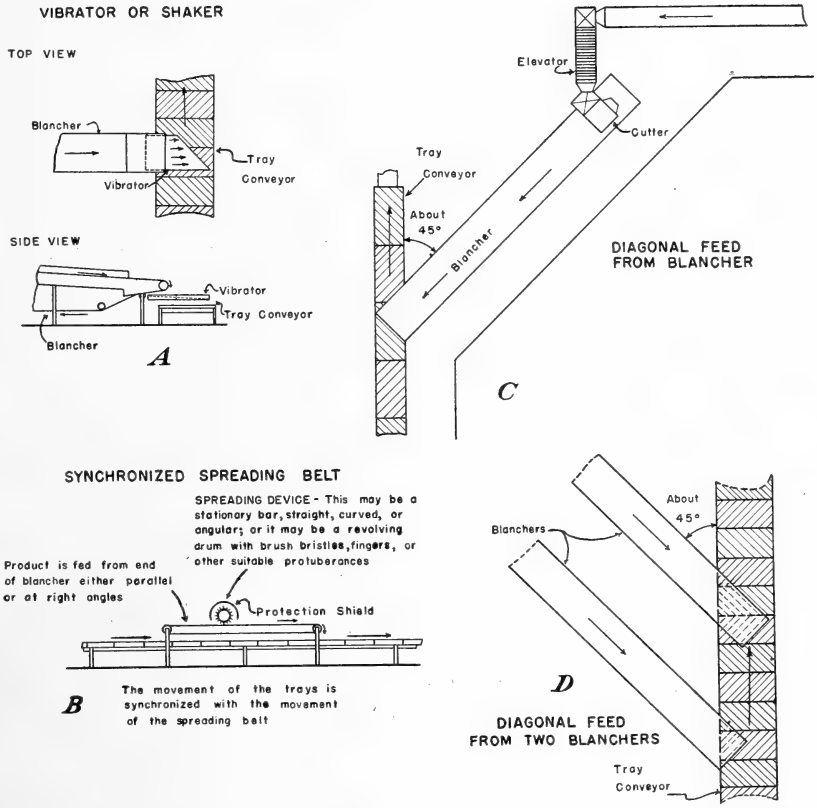

FIGURE 7.—Various methods of automatically spreading product on trays: *A*, Vibrator or shaker type of spreader; *B*, spreader utilizing spreading belt located above trays; *C*, a 4-foot blancher will spread evenly across 3-foot trays, at approximately a 45° angle. This lay-out is designed to fit into floor plan shown in figure 2. *D*, two blanchers, each 4 feet wide, will spread evenly across 6-foot trays at approximately a 45° angle.

It is important that tray handling be avoided wherever feasible. One possibility is illustrated in figure 8. After the trays are scraped and dumped, they are placed immediately on the tray conveyor which takes them back to be loaded again. Tray cleaning can be accomplished on this conveyor by means of high-pressure, hot-water sprays, revolving brushes, etc. A car standing alongside the conveyor can be used to furnish extra trays when necessary. Two conveyors in series, the first running at a faster speed, help to maintain a continuous line of trays for loading. If this system is used, tray scraping and tray loading must be coordinated for efficient operation.

Some operators have found it necessary, when using wooden trays, to soak them before they are washed in order to obtain satisfactory cleaning. Trays so washed must be dried under proper conditions to avoid damage from checking. It is desirable to dry the trays before reloading so that the large amount of water carried in the wet wood will not cause an increase in the drying time and a corresponding decrease in quality of the vegetables being processed.

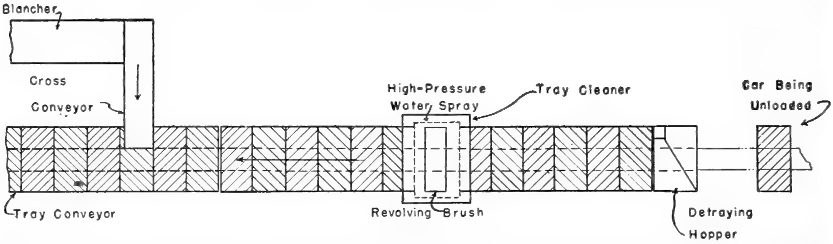

FIGURE 8.—Lay-out of tray line to avoid excessive handling of trays between unloading and loading.

Packaging Room

The packaging room should be enclosed, thus excluding damp air from the preparation room and dehydrator. Air-desiccating equipment is advisable in many cases. If a refrigeration system already is available, desiccation based upon refrigeration can be used. Where no such equipment exists, nonrefrigerative types are generally installed. When a product is dried to an extremely low moisture content, desiccation of air is essential and will more than pay for itself in improving the quality of the packaged material.

Where a shaker-sieve is used to remove the fines from the dried product, the economical use of these fines is a problem. If the quantity is large, installation of grinding equipment may be advisable. The necessity for grinding equipment also depends largely upon the demand for soup stocks, purees, and seasonings. Onions, celery, and garlic have been quite generally prepared in powder form, and powdering equipment will probably continue to find its greatest use for these vegetables. An extremely dry product and dry air are essential in any powdering operation.

Plant and Equipment Costs

The costs of the building and equipment vary considerably. The construction of new buildings or the use or rental of old buildings, the purchase of new or second-hand machinery, and the wide variation possible in the type and size of each item of equipment are factors that make an over-all estimate unreliable in many cases. As a guide, however, tables 2 and 3 have been prepared. Table 2 presents rough cost estimates for the preparation, final inspection, and packaging equipment indicated in figures 1 to 5. Table 3 gives the approximate costs of constructing and equipping these same plants, including all usual items.

Table 2.—*Preparation, final inspection, and packaging equipment costs for dehydration plants handling carrots, potatoes, rutabagas, and sweetpotatoes*

Item	5-ton plant [1]		25-ton plant [1]		50-ton plant [1]		100-ton plant [1]	
	Low	High	Low	High	Low	High	Low	High
Preparation equipment:								
Hand trucks	$15	$25	$50	$100	$100	$150	$100	$200
Conveyors			500	800	800	1,000	1,000	1,500
Elevators			500	700	600	800	800	1,000
Washer	300	600	600	800	1,000	1,200	1,100	1,400
Peelers	300	500						
Peeling scalders			1,000	1,500	1,500	2,000	2,500	3,000
High pressure washers and pumps			1,000	2,000	1,500	2,500	2,500	3,000
Trimming belts or tables	75	100	1,500	3,000	2,000	4,000	4,000	8,000
Conveyors and elevators			600	1,000	800	1,200	1,500	2,000
Cutters	500	700	800	1,300	800	1,300	1,500	2,500
Blanchers	1,000	1,200	2,000	3,000	3,000	5,000	6,000	10,000
Total	2,190	3,125	8,550	14,200	12,100	19,150	21,000	32,600
Final inspection and packaging equipment:								
Hoppers and shaker sieves	50	100	300	500	400	600	400	600
Inspection belts			400	600	600	1,000	1,000	1,400
Hoppers, scales, and packaging equipment	100	150	300	600	400	800	500	1,000
Roller conveyor			200	400	250	500	400	600
Hand trucks and tools	50	100	100	200	150	300	250	400
Total	200	350	1,300	2,300	1,800	3,200	2,550	4,000
Total cost of equipment	2,390	3,475	9,850	16,500	13,900	22,350	23,550	36,600
Approximate installation costs (25 percent of equipment)	600	850	2,450	4,100	3,500	5,600	5,900	9,150
Total cost installed	2,990	4,325	12,300	20,600	17,400	27,950	29,450	45,750

[1] Capacity given in tons per 24 hours, unprepared basis.

Table 3.—*Building and equipment costs exclusive of boiler equipment*[1] *for dehydration plants handling carrots, potatoes, and rutabagas*[2]

Item of plant	5-ton, counterflow tunnel type [3]		25-ton plant, conveyor type [3]		25-ton plant, counterflow tunnel type [3]		50-ton plant, counterflow tunnel type [3]		100-ton plant, multistage tunnel type [3]	
	Low	High	Low	High	Low	High	Low	High	Low	High
Preparation, final inspection, and packaging equipment	$3,000	$4,300	$12,000	$21,000	$12,000	$21,000	$17,000	$28,000	$29,000	$46,000
Drying equipment	4,000	6,000	30,000	35,000	12,000	15,000	25,000	30,000	50,000	60,000
Building space at $1 per square foot	2,600	5,000	10,000	17,000	11,000	18,000	20,000	32,000	33,000	57,000
Sewerage			1,000	2,000	1,000	2,000	2,000	3,000	3,000	4,000
Office and laboratory equipment	100	500	500	1,000	500	1,000	500	2,000	1,000	3,000
Machine shop tools and equipment	100	200	250	500	250	500	500	1,000	500	1,500
Total cost exclusive of boiler equipment [1]	9,800	16,000	53,750	76,500	36,750	57,500	65,000	96,000	116,500	171,500
Cost per ton of daily capacity (unprepared basis)	2,000	3,200	2,200	3,100	1,500	2,300	1,300	1,900	1,200	1,700

[1] No cost allowances are included for boilers because many dehydration plants install second-hand boilers at a fraction of cost of new ones. For example, 1 plant purchased a second-hand 125-horsepower boiler at an installed cost, including accessory equipment, of approximately $8,000.

Estimates of costs of new boilers including piping and auxiliaries, but not foundations or buildings, are as follows (from 1 to 2 boiler horsepower are required for each ton of daily capacity, unprepared basis, for blanching and incidental uses only):

Developed horsepower:	*Price per horsepower*	Developed horsepower:	*Price per horsepower*
25	$250	200	$125
50	200	300	100
100	170	500	70

[2] Because of their drying characteristics, sweetpotatoes are not included. The drier and the floor-space requirements are different because of the need for more tray area.

[3] Capacity given in tons per 24 hours, unprepared basis.

The over-all costs, as given, without boiler equipment, vary from $1,200 to $3,200 per ton of daily capacity, unprepared basis, depending upon the size and type of plant and the low-high limits upon which the estimates are based. The low cost of $1,200 for the 100-ton plant and the low limits for the other sizes cannot be considered practical since they are a summation of the low estimates for the items of equipment.

There is only a remote likelihood that any plant will or should be constructed at a minimum of cost for all items. Unless constructed under unusual circumstances, such a plant would probably have op-

TABLE 4.—*Capacities per unit of time in a vegetable-dehydration plant capable of handling 50 tons per day, unprepared basis*

Item	Table beets (slices)	Cabbage (shreds)	Carrots (cubes)	Onions (slices)	Potatoes (strips)	Rutabagas (slices)	Sweetpotatoes (slices)
Unprepared basis:							
Weight per hour (operating 21 hours per day) ---pounds--	4,750	4,750	4,750	4,750	4,750	4,750	4,750
Weight per minute ---do---	80	80	80	80	80	80	80
Women coring (estimated) --number--	--------	6	--------	--------	--------	--------	--------
Weight per woman per minute pounds--	--------	13	--------	--------	--------	--------	--------
Prepared basis:							
Assumed culling, peeling, trimming loss ---percent--	25	25	20	10	25	15	25
Weight per hour (operating 21 hours per day) ---pounds--	3,570	3,570	3,810	4,290	3,570	4,050	3,570
Weight per minute ---do---	60	60	64	72	60	68	60
Women trimming (estimated) number--	23	--------	20	30	40	20	30
Weight per woman per minute pounds--	2.6	--------	3.2	2.4	1.5	3.4	2.0
Assumed blancher loading per square foot [1] ---pounds--	(2)	2	4	(3)	4	4	4
Assumed blanching time ---minutes--	(2)	3	6	(3)	6	6	6
Weight in blancher at any one time [4] pounds--	(2)	180	380	(3)	360	405	360
Active blancher surface ---square feet--	(2)	90	95	(3)	90	100	90
Assumed tray loading per square foot pounds--	1.4	1.0	1.5	1.25	1.25	1.4	1.25
Weight per 3 by 6 tray ---do---	25	18	27	22.5	22.5	25	22.5
Weight per 22-tray car ---do---	550	395	595	495	495	550	495
Cars per hour [4] ---number--	6.5	9	6.4	8.7	7.2	7.4	7.2
Time per car ---minutes--	9.2	6.7	9.5	7	8	8	8
Trays per hour [4] ---number--	145	200	140	190	160	160	160
Trays per minute ---do---	2.4	3.3	2.4	3.2	2.7	2.7	2.7
Time per tray --- seconds--	25	18	25	19	22	22	22
Approximate active length of blancher 6 feet wide, if product is blanched on 3 by 6 trays ---feet--	--------	30	45	--------	50	50	50
Dried basis:							
Assumed over-all shrinkage ---ratio--	13 to 1	20 to 1	11 to 1	[5] 11 to 1	7 to 1	10.5 to 1	5 to 1
Weight per day ---pounds--	7,700	5,000	9,100	9,000	14,300	9,500	20,000
Weight per hour (operating 21 hours per day) ---pounds--	365	240	430	430	680	450	950
Weight per minute ---do---	6.1	4	7.2	7.2	11	7.5	16
Weight per 5-gallon package (estimated) ---pounds--	8	7	17	12	10	12	12
Packages per day ---number--	960	715	535	760	1,430	790	1,670
Packages per hour (operating 21 hours per day) ---number--	46	34	25	36	68	38	80
Time between packages ---minutes---	1.3	1.8	2.4	1.7	0.9	1.6	0.8

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[1] Recent experiments indicate that under best blanching conditions the blancher can be loaded more heavily than indicated. Some uncertainty also exists in regard to the blanching time required to secure satisfactory results. At high blancher loading, the retention time must be longer; conversely, at light loading (e. g. on trays) time may be shorter.

[2] Precooked whole.

[3] Not blanched.

[4] The blancher size and the number of trays and cars handled are based on the total weight of trimmed material. The actual weight handled will decrease during washing, cutting, and blanching, because of leaching and loss of fines. On the basis of the loadings indicated, the size of the blancher and number of trays handled will, therefore, be somewhat less than shown.

[5] The over-all shrinkage ratio of onions may vary from 8 to 1 to 14 to 1, depending on the variety and condition of the raw material. The ratio of 11 to 1 has been accepted for estimating purposes only.

erating difficulties due to lack of equipment and limited floor space. Dehydration plants should be balanced units, and the costs of various parts will be low or high in accordance with the circumstances affecting each particular machine, operation, or floor-space requirement.

These costs must be considered as only very rough estimates since they cannot possibly include all items. Even a plant that has been completely engineered before construction may present the owner with additional cost items before it is finished. Conditions vary throughout the country, and these variations materially affect any attempt to arrive at generalizations regarding costs.

Handling Capacities and Utility Requirements

The capacities per unit of time at various points along the processing line of a 50-ton plant are shown in table 4. Data are given for seven vegetables important in the present program. Such tables are of assistance in estimating labor requirements and equipment sizes for each operation.

Facilities must be available to provide approximately the quantities of heat, power, and water indicated in table 5. The figures in this table allow for the differences in consumption of utilities under various operating conditions. The indicated demand load for electric power is really total connected load. The average operating load will usually be smaller.

TABLE 5.—*Approximate utility requirements for dehydration plants of various sizes*

Utility and application	Requirements per hour for plant of—		
	100-ton	50-ton	25-ton
Water:			
Potatoes and sweetpotatoes ... gallons	10, 000–20, 000	5, 000–10, 000	2, 500–5, 000
Carrots, beets, rutabagas, and onions ... do	8, 000–16, 000	4, 000–8, 000	2, 000–4, 000
Cabbage ... do	2, 400–4, 000	1, 200–2, 000	600–1, 000
Electricity:			
Demand load ... kilowatts	150–250	80–125	50–70
Fuel:			
Dehydrator:			
Direct heat ... millions B. t. u.[1]	15–20	7½–10	3½–5
Indirect heat ... do.[1]	30–50	15–25	8–13
Steam heat ... do.[1]	20–30	10–15	5–8
Blancher[2] and incidental ... do.[1]	4–8	2–4	1–2
Boiler capacity:			
Blanching and incidental ... boiler horsepower[1]	100–200	50–100	25–50
Dehydrator ... do.[1]	500–700	250–350	125–175

[1] The lower limits of heat requirement and boiler capacity for the dehydrator are considerably larger than needed for some vegetables under good operating conditions. On riced potatoes, for example, the minimum heat requirement may be less than two-thirds of that indicated.

[2] Low limit is based on continuous-type blancher. If batch-type blancher is used, the blanching steam demand will be higher.

The quantity of heat required varies widely with different methods of air heating and from one vegetable to another. The necessary size of steam plant, even on the same operating procedure, varies with boiler efficiency and care exercised in avoiding steam waste. The lower limits of heat and steam requirement for the dehydrator are considerably higher than the actual operating usage for some vegetables under good operating conditions. They allow a margin of safety adequate to permit full-capacity operation at all times, even under bad atmospheric conditions. Many operators will not find it necessary to have such a large amount of surplus heating capacity.

STORING AND HANDLING FRESH FRUITS AND VEGETABLES

Proper handling of fresh produce is an important step in the preparation of a high-quality dehydrated food. Serious losses in edible quality and nutritive value may take place as a result of failure to recognize the perishable nature of vegetables and fruits. Rots may attack even the least perishable commodities and make them unfit for use. Spinach, sweet corn, and peas, for example, are so perishable that they should be processed within a few hours after harvest. If unavoidable delays are experienced, such products require refrigeration to slow down deterioration. Others, such as potatoes, can be held for some time without refrigeration but they should be protected from the sun and from heating.

Receiving the Product

The minimum requirement at the dehydration plant is a receiving shed where the fresh produce can be stacked out of the sun, wind, and rain as it is delivered from the field. In cold climates a tight, insulated building is needed. When produce is received during warm weather and is to be held overnight or all day before processing, it should not be stacked tightly; instead, an air space should be left on two sides of the containers to permit ventilation and prevent heating. All produce generates heat; leafy products generate enough to cause deterioration in a short time if stacked in unventilated piles.

Produce is delivered to the dehydrating plant in many types of containers, the selection being dictated by experience. Ventilated crates or hampers, or small lug boxes are often used for such perishable commodities as peas, corn, and spinach, and crushed ice is sometimes packed in the middle of the container to prevent heating during long-distance shipment. Shallow field boxes are widely used for stone fruits, apples, pears, and some vegetables, and bushel boxes, baskets of various sizes, and barrels are used in other districts for fruits and vegetables. Such vegetables as potatoes, onions, and other root crops are commonly sacked.

It is often more convenient and better practice to handle the commodity in the field container rather than to empty it into bins. Emptying it into bins entails extra handling, increasing chances of bruising, and necessitates provision for ventilation if the produce is to be held for some time. Some products, for example cabbage, carrots, or other root crops, may be delivered in bulk, and receiving bins are then used to good advantage.

Storage

Since a long season of operation is advantageous, the problem of laying up a supply of raw material is important. Storage facilities will also aid in smoothing out production peaks and preventing shutdowns. If commercial storage plants or suitable farm storages are conveniently located, they can be used. It may be necessary, however, for the operator to provide his own storage, and how elaborate this will have to be will depend upon the storage requirements of the commodity, on the temperature and humidity it needs, the normal storage life, and whether or not outside temperatures can be used to approximate these requirements. For the storage of root crops, such as potatoes and carrots, in the cool fall months nothing more than a covered shed may be needed. The special requirements of each crop are discussed in a later section of this publication and these, together with commercial experience in the district, should be consulted to determine whether or not unrefrigerated storage will suffice. Plans for farm storage plants that use outside air to maintain temperatures can be obtained from the United States Department of Agriculture, Washington, D. C.

If refrigeration is needed, the kind of plant that is installed will be determined by the availability of equipment and the investment warranted. Storages refrigerated by ice bunkers and fans instead of mechanical refrigeration have been constructed in recent years for crops that have a short season, such as stone fruits and grapes. The initial investment is lower than for mechanically refrigerated plants and desirable humidities of 85 to 90 percent are easy to maintain. Combination ice-bunker and mechanically refrigerated plants have been constructed that utilize the high refrigeration capacity of ice bunkers to cool the commodity and a small compressor to maintain temperatures during storage. The more common type is the storage plant refrigerated entirely by mechanical refrigeration, and it may be one of several designs.

Whatever the type of plant installed, it should have refrigeration capacity sufficient to cool the produce to within a few degrees of the recommended storage temperature in 18 to 24 hours, and it should maintain temperatures throughout the rooms within a degree or two of the specified temperature. The correct humidity should also be maintained within 2 or 3 percent. These specifications if insisted upon will insure ample refrigeration capacity, good air volume and distribution, and suitable air-temperature control. The lay-out of the plant for convenience in loading and unloading will likewise be an important matter to discuss with the engineer designing the plant.

Transportation

If the dehydration plant is located close to the area of production, as it should be, there will be few transportation problems. Generally the methods found adequate for the trucking or carlot shipment of produce for the fresh market should suffice for the dehydrator. When perishable crops, such as spinach, asparagus, peas, and sweet corn, are to be in transit for 10 or 12 hours or longer, icing the container or the load with crushed ice will help to preserve quality and nutritive value. This may be advantageous for even shorter hauls.

String beans, which are often harmed by wetting, may be benefited by precooling in cold air before shipment. For products that are shipped some distance, refrigerated trucks or refrigerator cars will be needed. The refrigerator car lines serving the district can be consulted as to the refrigeration services in general use for specific commodities. A new type of car, equipped with fans to circulate air in transit, is available in limited quantities in some districts. These provide better refrigeration in transit than standard cars, and will be found especially adaptable to perishable commodities that are shipped without top icing the load.

PREPARATION OF RAW MATERIALS

Washing

Root vegetables.—Root crops received from the field are sometimes laden with mud and debris, and must be thoroughly cleaned before they are peeled, since dirt or sand on the vegetable will interfere with any kind of peeling operation. The difficulty of cleaning depends on such factors as type, variety, age, and condition of the product, as well as type and condition of the soil. In localities where produce has previously been prepared for the fresh market, adequate cleaning procedures have probably already been established. In such cases, it is suggested that a study be made of the adaptability of these methods to a new processing line.

Root crops are usually cleaned in two or more steps. A dry shaker screen will remove much loose dirt and trash. Loose dirt is then washed away in a water spray or bath. The equipment required for this preliminary wash is generally incorporated into a unit which performs a dual function. For spray washing the sprays are located on the elevator, which also serves as a conveyor to the main washer; for washing in a bath the product is allowed to soak in the boot of the same elevator. The latter method is preferred, as it tends to even out the surges caused by intermittent loading (fig. 9).

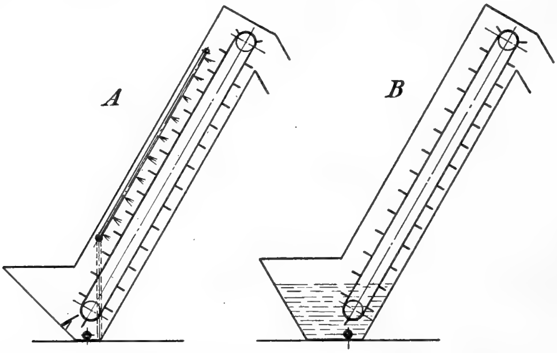

FIGURE 9.—Elevators: *A*, Equipped with water sprays; *B*, equipped with boot washer.

The final washing operation can be carried out in any of several commonly used types of washers, such as the rotary drum, the brush, and the shaker washer. Most of these units are equipped with water sprays, the intensity of which may range from normal city water pressure to several hundred pounds per square inch. High-pressure water sprays ordinarily require the use of booster pumps.

Because of its simplicity, the rotary-drum washer is the one most widely used. The severity of its action can be varied by changing the roughness of the drum surface. If longitudinal slots are used, open spaces between the slots will facilitate the ejection of sticks, rubble, and peewee-sized products. The retention time will determine the degree of washing for any given washer. Control of this factor in a continuous washer can be accomplished by varying the degree of tilt of the drum, varying the drum speed, or more positively by providing an internal helical guide fence to regulate the advance of the product.

Batch-type drum washers are generally suitable only for use in the very smallest dehydration plants, or in connection with institutional or community dehydrators.

The brush washer is quite commonly used, but it is limited because of mechanical complications due to brush failure. The product in the washer is caused to pass over or along between rotary brushes. These brushes are usually made from water-resistant, tough fiber bristles or, in some cases, of rubber fingers. The adjacent brushes usually run in alternate directions or at different speeds in such a way that the product is rotated and brushed simultaneously as it progresses. The retention time is governed by the flight path or by the rate of charging, which has the effect of crowding the washed product out of the washer. The units are best suited to removing sandy loam but may be used to remove heavier soils.

Shuffle or shaker washers, although very efficient, are mechanically complicated. Their vigorous reciprocating action produces violent scrubbing and tumbling of the product, and hence even the most stubborn mud can be removed. When equipment of this type is used the supporting structure must be firm in order to prevent objectionable vibration.

In any type of mechanical washer the rubbing and abrasive action can be powerfully reinforced and supplemented by proper distribution and control of the supply of wash water. The water may have two distinct functions. When it is supplied in the form of vigorous sprays it has a very effective scouring action which will cut away tightly adhering patches of clay and dislodge dirt from the bottom of wrinkles and eyes that are out of reach of surface rubbing or brushing. In addition, the flow of water down over the material flushes away the loosened dirt and removes it from the washer. Both of these actions are desired. The first calls for sufficient water pressure and careful placing of the sprays. The second calls for a sufficient volume of water. In a rotary-drum washer the stream of vegetables is carried by the rotation of the drum well up on the ascending side of the drum, whence they are constantly rolling downhill toward the bottom. The water sprays should be carefully directed to cover thoroughly this sector on the ascending side of the drum.

Drain lines beneath vegetable washers should be provided with easily accessible dirt traps, since much of the dirt and sand carried by the wash water will be so heavy as to settle immediately in an ordinary sewer line and plug it.

The amount of washing required will vary throughout the season, and therefore ample facilities should be provided to care for the product under the most adverse conditions. The installation should also be sufficiently flexible to permit rearrangement of the equipment whenever necessary.

Loose leafy vegetables.—Cut vegetables, such as spinach, chard, parsley, etc., are usually washed in drum washers fitted with water sprays, or in tanks. The former means offers a continuous process and is, therefore, most commonly used. Shuffle and brush washers are obviously unsuitable.

Retention time in a drum washer will vary with the condition of the product, and the character and quantity of soil to be removed. Spray nozzles that provide a good scouring action without tearing, ripping, or otherwise injuring the product should be chosen.

Cabbage.—Head cabbage requires special handling during washing to prevent breaking up of the head. Usually, to prevent double handling, the loosened and damaged leaves are removed and the product is cored and quartered before washing. In this condition the leaves are loose and the head may be broken if it is roughly handled. Since most of the dirt and other foreign material is removed along with the loose and damaged leaves, washing becomes relatively simple. In most cases the cored and quartered product is placed on a wire-mesh belt conveyer and sprayed from above and below so as to dislodge entrained soil. Consideration should be given to the use of a water flume for conveying and cleansing the cabbage simultaneously; it is probable that eddy currents caused by the water in motion would bring about effective washing.

Grading

Following the washing operation it may be desirable to pass the product over an inspection belt for the removal of cull and foreign material, especially if the lot is of poor quality. This will be useful in saving time in the subsequent trimming and inspection operations.

Size grading of raw vegetables is a desirable operation to reduce peeling losses, especially when abrasive peeling is practiced. This use is discussed more thoroughly under the subject of abrasive peelers. If root vegetables are to be blanched or cooked whole, grading to size is almost essential to assure uniformity of cooking.

Size grading may be accomplished either manually or mechanically. Manual grading can be confined to removal of culls and other undesirable products, or special grading tables can be used which permit each inspector to grade the product into several sizes. By a system of belts and dividing fences, inspectors segregate the product into lots according to size. The equipment is in general similar to that usually employed for grading potatoes. As would be expected, the process requires semiskilled inspectors or operators.

Mechanical graders are available in several types. The most common are the rubber-spool grader, the rotary-drum grader, and the shuffle grader. All operate by rolling the vegetable over a support fitted with openings that are small at the entrance end and larger further along, so that pieces of different sizes drop through at different places. In general, selection of a grader should be governed by its ruggedness and reliability. The unit likely to require the least maintenance should be selected, all other conditions being equal.

To summarize, it can be said that grading has application if field-run products are handled, if selective grading for marketing purposes is desired, or if abrasive peeling or cooking of the whole vegetable is practiced.

Root Peeling

A satisfactory peeling method is of vital importance to all dehydration plants handling root crops. Unsatisfactory or inefficient peeling may spell the financial doom of an otherwise successful plant.

The peeling method should be selected only after careful weighing of labor cost against cost of raw product. Other considerations that affect the selection are available means of waste disposal, uniformity of the product size and quality, and ability of the product to resist discoloration or damage during or after peeling. The most commonly used peelers for root products are the abrasive, brine, flame, lye, and retort peelers. Brief discussions of the units are presented below.

Abrasive peelers.—Abrasive peelers are suitable for processing all root vegetables and are generally divided into two groups, the batch or bucket type and the continuous. The first consists essentially of a cylindrical abrasive-lined drum having a revolving abrasive bottom or floor plate, and is provided with water sprays. A side door facilitates removal of peeled product. When in operation, the product is dumped into the drum and the revolving floor plate jostles the vegetables, causing them to be thrown against the sides and bottom until all surfaces are rubbed smooth and the skin removed. The flow of water flushes the finely divided skin through a waste opening in the bottom. Naturally the operation must be continued until all protuberances are ground away if the valleys, eyes, and imperfections are to be removed (fig. 10).

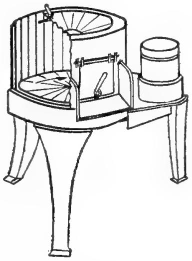

FIGURE 10.—Batch-type abrasive peeler.

The continuous abrasive peeler works on a slightly different principle (fig. 11). The product passes in a circuitous course among and over the rotating abrasive cylinders. Water sprays flush waste material away. The rate of feed determines the retention period in a peeler of this type.

Skill must be exercised in determining the proper degree of abrasive peeling. If the product is retained for a relatively short time, only partial peeling will be accomplished. Excessive retention will result in excessive waste. Since the weight of the product governs the pressure at the region of contact, the rate of peeling will vary according to the size and shape of the product. Flattened pieces which refuse to roll may be entirely ground away.

If hand peeling is depended upon to finish the semipeeled product, a balance must be struck between the cost of hand peeling and the cost of raw material. As machine peeling is increased, the waste of flesh underneath the skin increases, but the amount of hand peeling required becomes less.

As previously pointed out, products of different sizes peel at different rates, and if peeling is to be accomplished at maximum efficiency, grading is necessary. Plants operating on potatoes have experienced as low a recovery as 60 percent (40 percent peeling and trimming loss). At best the peeling and trimming loss with abrasive peelers and hand finishing will be in excess of 20 percent.

The abrasive peeler is being replaced in a large number of plants by more efficient peeling methods. In general the field in which abrasive peelers are best suited comprises relatively small and intermittent operations, which include not only community and institutional dehydration, but also restaurants and Army kitchens.

Brine peeling.—Brine peeling, recently developed, may be found suitable for peeling potatoes, rutabagas, sweetpotatoes, and beets, but not carrots or parsnips. Essentially, the process consists of holding the washed vegetable immersed in boiling saturated salt-brine for a period ranging from 6 to 15 minutes, depending on the kind, variety, maturity, and condition of the product. After the skin has been adequately loosened, the product is removed from the boiling solution and placed in a rotary-drum slot washer having rough inner surfaces so that a violent tumbling action takes place under vigorous water sprays. Within a period of 1¼ to 2 minutes, the skin is removed from the flesh. Longitudinal slots between the corrugations permit the skins to be ejected from the washer as soon as they are removed. Hand trimming is reduced to a minimum.

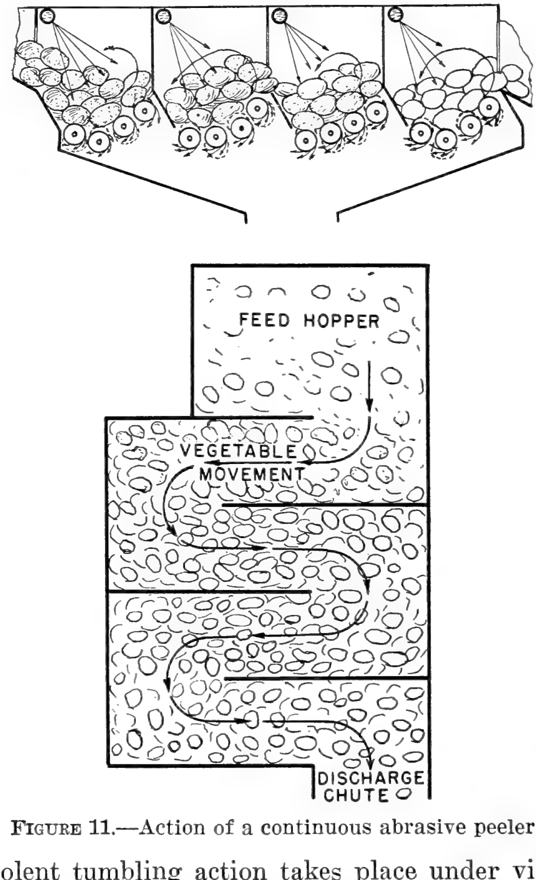

FIGURE 11.—Action of a continuous abrasive peeler.

The process works with varying degrees of success according to the character of the product. Provisions must therefore be made to allow considerable latitude in the choice of retention times for scalding and washing.

Figure 12 shows a unit satisfactory for use as a brine scalder. It will be noted that the product is advanced by the underside of the chain belt. This unit is limited to use on products which are light enough to float in the processing solution. The recovery after peeling and hand trimming that can be expected ranges, for potatoes, from 82 to 88 percent under normal operating conditions. Pregrading to size is unnecessary. The salt on the surface of the product retards discoloration due to oxidation.

Flame peeling.—Flame peeling has been variously popular over the last 10 years. It has been used with some success on carrots and potatoes and is particularly adaptable for use in removing the paper skins from onions. Essentially, a flame peeler consists of a device for transporting the washed vegetables through an oven which is kept at a high temperature by use of either gas or liquid fuel.

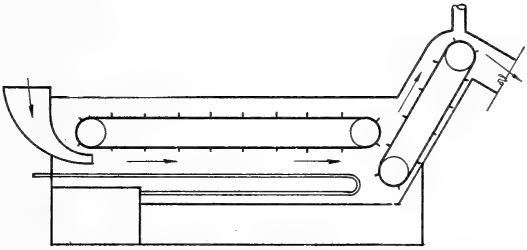

FIGURE 12.—A unit suitable for scalding in the brine-peeling process.

It has been found that when a product is subjected to temperatures of 2,000° F. or over for a period ranging from 15 to 30 seconds, the outer surfaces or peel will first be dried and then burned to a char. This carbonaceous layer can be removed by rigorous scrubbing and washing, leaving the product in a peeled condition. The application of intense heat results in carbonizing the outer surfaces before the heat has penetrated to an appreciable depth into the product. It has been found by test that the higher the temperature the shorter the necessary retention period and the smaller the depth of penetration of the heat ring.

Extensive tests on potatoes indicate that although the major part of the outside peel can be removed by the flame peeler-washer combination, deep eyes are not effectively removed. If the eyes are not peeled, considerable manual trimming will be necessary. It is doubtful that much time can be saved over that required for peeling the entire product by hand.

Some tests with onions have indicated that the char tended to mix with the natural onion oils to form an oil-smudge which is difficult if not impossible to remove from the surface. It is probable that a much briefer and more superficial treatment is necessary than would be suitable for potatoes or carrots.

Designers and builders of flame peelers face serious mechanical problems. Principally, these lie in the difficulty of conveying the product through the intense heat of the furnace. Several types of conveying means have been employed with varying degrees of success. One commercial design uses a large cylindrical rotating drum fitted with a refractory lining which is formed as a helical screw to convey the product through the furnace. Gas flame is used for heating. This flame is caused to impinge upon the refractory so that it becomes incandescent. Since the refractory tends to disintegrate if rapidly heated and cooled, the unit should be kept continuously hot insofar as possible.

Another device that has been used comprises spool-shaped rolls placed on a conveyor chain. These rolls support the product and rotate it continuously as it is being conveyed through the furnace. Still another device consists of a rotary drum constructed like a squirrel cage. The drum is built entirely of heat-resistant metal and the flame is located on the outside of the drum and is directed against the product. Still another system consists of long water-cooled rolls, and alternate rolls are fitted with helical screws suited to convey the product lengthwise of the rolls. All rolls rotate in the same direction and hence the potatoes are rotated as they are conveyed.

No matter what device is used for conveying the vegetables, its useful life will be limited by the high temperatures. After a careful study of flame- and radiant-heating devices, one would judge them to be relatively inefficient as compared with other devices available for peeling. The fuel costs are comparatively high considering the amount of work done.

Lye peeling.—Lye or caustic peeling is suitable for processing practically all root vegetables in either a batch or continuous process. The batch process is usually carried out by dipping the product in a hot caustic bath and is generally limited to small-scale operations. Continuous peeling is not thus limited.

The drum-type continuous caustic peeler consists of a drum rotating partially submerged in hot caustic solution. An internal helical fence advances the product through the bath at a selected rate. This method may be wasteful of lye and heat and is somewhat cumbersome for its capacity. It is also a source of personal hazard due to dripping and splashing of the lye unless the unit is well shielded to protect the operator from coming in contact with the lye.

The continuous tank peeler, equipped with a metal belt for submerging and conveying the product through the bath, has been the most successful type in operation. Capacity can be varied by lengthening or widening the draper belt. The belt is equipped with advancing flights of lugs to insure uniform conveyance through the tank. Means are provided for draining excess solution from the product prior to its departure from the tank. The time taken for draining should be considered in computing the retention time, because the lye is active until neutralized or washed from the product.

The most practical type of continuous tank peeler confines the conveyor belt entirely within the tank. This feature prevents excessive loss of heat and prevents dripping of the caustic outside of the tank. The belts are normally of very sturdy design, positively driven, and supported by chains so that frequent servicing is unnecessary.

The chemical action of the lye causes some surface disintegration of the product, forming a sludge which collects on the bottom of the tank. To facilitate drainage, the bottom of the tank should be sloped to a common low point, at which place a draw-off valve should be located.

Sufficient clearances must be provided in the tank to accommodate a suitable heating coil. The coil should be designed to heat the solution rapidly to the desired bath temperature and to maintain it there when the product is being introduced at normal rates. The coil should be located well above the sludge basin described above, so that normal thermal circulation will not continually agitate the sludge.

After the product has been chemically treated in the lye vat and drained, it goes directly into a washer for removal of skin and rinsing residual caustic solution from the peeled surface. The simple corrugated-surface rotary-drum washer equipped with moderately high-pressure water sprays has been used satisfactorily. It is suggested that the washer be proportioned to permit a retention time of not less than 1¼ minutes.

A simple test for detecting the presence of caustic on the surface of a washed potato consists of placing a drop of alcohol solution of phenolphthalein on the potato. The appearance of a pink stain will indicate that not all of the caustic has been removed, in which case additional washing is necessary.

The time of immersion in the caustic bath will depend upon several factors; namely, the strength of the caustic bath and its temperature, and the type, variety, and age of the product. A typical curve showing the approximate retention time for potatoes in different lye concentrations is shown on figure 13 (*48*).[2] Probably the best results can be obtained with moderately dilute solutions, inasmuch as the weaker solutions can be much more readily removed from the product in the washer than concentrated solutions. It is desirable that control runs be performed on each type of product to determine the correct retention time prior to full-scale operation.

Several means have been devised for maintaining constant bath concentrations, but none has been firmly established. A simple means is to keep close watch on the peeling results and add lye as required. After a brief period of operation, the operator will become skilled in determining the caustic requirements of the system per sack of product peeled.

Lye (commercial caustic soda) is obtainable in either flake or cake form. The former is more expensive but is more readily handled. Cake lye is more difficult to handle because it must be either broken up or melted through the use of a steam jet thrust into the container. It has the advantage, however, of being cheaper than the flake lye. In some localities commercial 50-percent caustic soda solution may be obtained in tank-car lots. It may be stored in steel tanks, which must, however, be provided with heating coils, since the freezing point of the heavy solution is about 53° F. The solution can be measured to the peeler by means of a weir or small measuring tank.

Retort peeling.—Retort or steam peeling has recently attracted attention, along with brine and flame peeling, as a heat process for peeling potatoes. Essentially, retort peeling consists of subjecting a product to steam under pressure for a short period, thus loosening the skins so that they can be removed by washing and scrubbing.

At least one commercial plant reports satisfactory results. Potatoes are subjected to steam under 50 to 60 pounds per square inch of gage pressure for a period of 30 to 45 seconds. This pressure corresponds to a temperature of about 300° F. At this temperature the flesh immediately adjacent to the skin is cooked to the softening point and the skins are removed in a washer.

In any type of equipment now commercially available, the proce-

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[2] Italics numbers in parentheses refer to Literature Cited, p. 216.

dure is essentially a batch process and the necessary equipment is heavy and somewhat difficult to obtain. The opening and closing of the heavy steam-tight doors, as is required in loading and unloading the equipment, is laborious and will undoubtedly require considerable time. This factor makes it desirable that the retort be installed in duplicate so that the batch peeling operation will furnish a steady flow of materials to the processing line.

Probably the steam process is satisfactory for peeling all root products with the exception of carrots and parsnips, the tissuelike skins of which cannot be readily removed from the product by washing without removal of a substantial part of the flesh. Development of a satisfactory continuous pressure cooker would remove the most obvious limitation of the process.

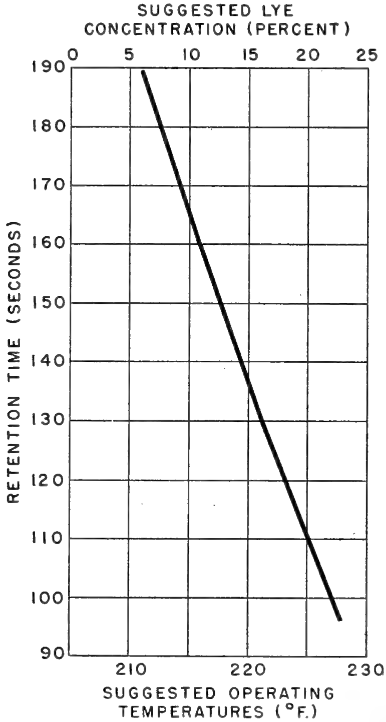

FIGURE 13.—Approximate retention time for potatoes in different concentrations of lye solution in preparation for peeling.

Summary of peeling methods.—Abrasive and lye peelers offer the most positive peeling results and are the most versatile for handling the entire range of root products. Of the two, the lye peeler offers the highest recovery of peeled and trimmed vegetable with the least labor. The costs of equivalent-size peeling equipment for lye and abrasive peeling are about equal. The personal hazard with lye peeling may limit its use. Retort peeling shows promise for most of the root vegetables, but suffers from the difficulties inherent in batch processes. Brine peelers offer high recovery with minimum manual labor, but are restricted to certain vegetables only. Equipment suitable for brine peeling is usually suitable also for lye peeling. The cost for equipment is considerably less than for retort equipment of similar capacity.

Flame peeling equipment is somewhat difficult to obtain and costly to operate. It is limited in field of application, depending upon the means used for conveying the product through the furnace. It is apt to be somewhat wasteful in fuel, and maintenance cost is exceptionally high. It is peculiarly suited to processing onions that cannot be readily peeled by other means.

All peelers, with the exception of abrasive, require an auxiliary washer to remove the peel and foreign material. The cost of the washer equipment is comparatively low, and no additional labor is required for its operation.

Trimming

Subsequent to peeling, the root crops require hand trimming for the removal of residual skin, eyes, discolored areas, digging cuts, disease and insect injury, sunburn, and green top. The amount required will depend upon the efficiency of the peeling operation.

The trimming of leafy vegetables involves hand removal of discolored leaves, disease and insect injury, and the removal of long, thick stems. In the trimming of cabbage, the wilted, soiled, or otherwise damaged outer leaves of the head are removed. Even if the outer leaves are in good condition, it is advisable to remove them to eliminate the danger from poisoning by spray residues, and operators should be careful to wash their hands thoroughly.

The next step in the preparation of cabbage involves removal of the core tissue which can be accomplished manually or mechanically. If the coring operation is to be done manually, care should be taken to keep the amount of cutting required to a minimum. Figure 14 shows two methods of cutting for coring. The first and preferred method (*A*) minimizes the necessary hand work. The cabbage is first cut along line 1. Part I is then complete. Next, the cabbage is cut along line 2, and part II is then complete. Part III is then cut along line 3 to remove the core. If the cabbage is cut as shown in figure 14, *B*, not less than six knife operations are necessary instead of three as required by the former method.

Some plants have improvised stationary cylindrical cutter knives for removing the core after operation 1 of the first process described. This stationary cutter knife is shown in figure 15. In using this device the operator may hold the part of the cabbage containing the core in two hands and use the entire strength of both arms for performing the coring operation. This method of coring is relatively simple and if carried out successively by two operators as a team wherein one operator divides the cabbage into two parts and the second operator removes the core, coring can be accomplished fairly rapidly and efficiently. This device permits removal of crooked cores, a feature which cannot readily be accomplished by mechanical coring.

When cabbage is prepared by mechanical coring, a rotating auger is provided. This auger should be of the self-centering type and designed for safe operation. Cutter knives are usually formed of tool steel in such a manner that when the cabbage is pressed upon the auger, it will start cutting. The device should not be self-starting as this feature might result in serious accidents to the operator. Mechanical coring is usually carried out on a complete head of cabbage. The difficulty with the operation is that after coring, the operator cannot be certain that the complete core has been removed. Even though the core is completely removed, it would seem desirable at least to cut the head in half to make certain that the inside tissue is free of insect and disease injury, such as black leaf speck and red heart. Failure to reject such heads will lead to increased inspection costs for the dried product and possible rejection of the product on the basis of defects above the tolerance permitted. The system also has a disadvantage in that if loose heads are being processed, the complete cabbage may disintegrate during the coring operation, thus causing considerable waste. In some foreign countries, the core is sliced finely and dried along with the cabbage. This process is not permissible under United States Government specifications. After coring has been accomplished, the product is washed as described in the section on washing.

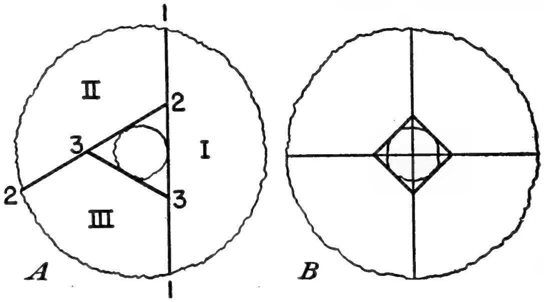

FIGURE 14.—Methods of coring cabbage by hand: *A*, cutting to minimize hand labor. Only three knife cuts are necessary. *B*, six knife cuts are necessary.

Many types of trimming tables are in commercial use. Probably the most common for root vegetables is the straight-flow type in which a belt carries the untrimmed product along each side of the table, and the trimmed material is placed on a center belt which may be at the same level as the side belt or elevated to allow room for a return belt (figure 16). The "merry-go-round" type of trimming table has proved very popular. The product is brought around again to the trimmers if it is missed the first time.

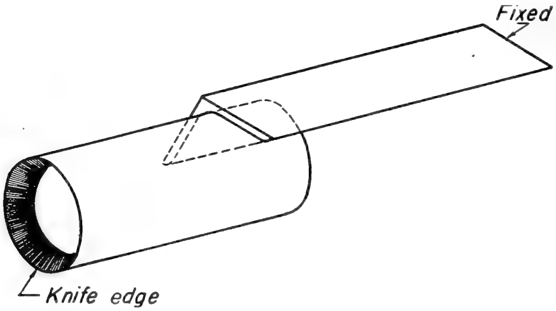

FIGURE 15.—Stationary knife for coring cabbage.

Some operators prefer a type of trimming belt which permits a definite check on the work of each trimmer. This may be accomplished by having the feed belt move forward intermittently, each trimmer handling all the material on a definite section of the belt. In another type the operator opens a gate from a central feed line and puts the trimmed vegetables through a counter chute. The trimmings in all these cases may either be carried away on a belt or put into a receptacle provided for each trimmer so that individual trimming losses can be determined.

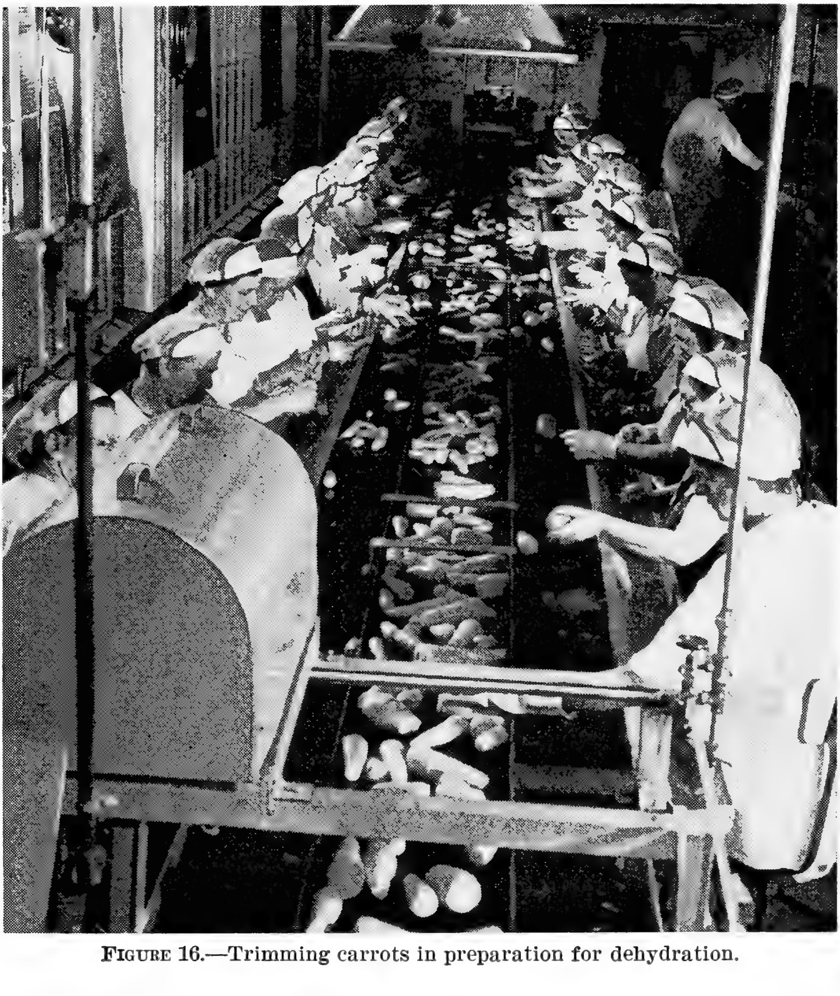

Figure 16.—Trimming carrots in preparation for dehydration.

In planning the trimming belt it is preferable to allow about 3 feet of space for each worker. It is possible to operate with only 30 inches with some crowding, but it is not desirable to plan on this basis. The larger allowance makes possible the addition of extra workers if needed.

Preparation labor varies considerably for different vegetables.

Five to ten trimmers may be required in a 50-ton cabbage plant (unprepared basis); from 15 to 25 for the same tonnage of carrots, rutabagas, or beets; from 25 to 35 for onions or sweetpotatoes; and from 30 to 50 for potatoes at the same tonnage input on an unprepared basis.

Cutting

Following the trimming operations the product passes to the cutting equipment where it is cut into the desired form and size. For the root crops the form may be strips (julienne), slices, or cubes, depending on the market demand. The size of the cuts is governed by the market requirements, the effect of size on drying rate (the larger the size the longer the time required for drying), and the characteristics desired in the finished product. The different cuts are as follows:

Slices one-eighth to one-fourth inch thick.
Strips three-sixteenths to three-eighths inch wide or thick and not less than three-fourths inch in length.
Cubes three-sixteenths to three-eighths inch on a side or half cubes.

From the standpoint of the conservation of shipping space the cubes are preferred, since they make a more solid pack than the slices or strips; that is, more weight can be packed into a given volume.

Several types of machines are manufactured for the cutting of root crops into the desired forms and sizes. A very flexible type is one that can be used for the cutting of all three forms into different sizes by simply changing the cutting parts.

Leafy vegetables, with the exception of cabbage, usually do not require division into smaller pieces after trimming. Cabbage requires cutting or shredding into pieces ranging from one-eighth to one-fourth inch in width. The larger width is preferred, since there is likely to be less loss of ascorbic acid from the product. The machinery used for the cutting or shredding of cabbage for dehydration is the same as that used by sauer-kraut manufacturers and canners.

For the cutting of root crops, machinery capable of handling from a few bushels to 12,000 pounds per hour, depending on the form and size of the piece, can be obtained. For cabbage, cutters handling from 10 to 50 tons per days are available.

The knives on the cutting machinery should be kept sharp because the use of dull knives will result in pieces of irregular shape and lacking in well-defined cut surfaces. Furthermore, considerable bruising of the tissues will occur, which has the effect of accelerating the metabolic processes, leading to rapid deterioration of vitamin quality as well as some other quality factors. As a safeguard against serious damage to the knives, precautions should be taken to remove small rocks, bolts, nuts, and nails. This may be accomplished by passing the material over a shaker screen with strong sprays of water. A magnet can be used just ahead of the cutter to take out tramp iron missed in the screening operation. Much damage and lost time can be avoided by such simple precautions.

Washing of the cut product is desirable for sanitary reasons, for the removal of foreign material and fines, and, in the case of starchy vegetables such as potatoes, for the removal of loose starch from the cut surfaces. The presence of the water film on the cut surfaces also tends to protect the product from discoloration by oxidation in traveling from the cutter to the blancher. This operation is usually accomplished by means of cold-water sprays over the conveyor leading from the cutter.

None of the cutting equipment mentioned above is suitable for producing a riced product. Ricing equipment is usually one of three types: namely, rotary, screw, or plunger. The essential action of each consists of mashing the product and extruding it through perforations of suitable size, not exceeding three-sixteenths inch in diameter.

For ricing, the product is first thoroughly cooked, and best results are usually obtained if the operation is carried out while the product is still hot. If the product becomes cool, it may become pasty or gummy, which will make it difficult to obtain a uniform spread on the drying trays.

In the preparation of material for ricing, the precooking can be carried out on the sliced, whole, halved, or quartered product. The procedure using slices is probably best from the standpoint of practical operation and labor saving, since slicing can be accomplished mechanically while halving or quartering is accomplished by hand labor. Furthermore, slices can be cooked throughout, without overcooking the surface. Cooking the whole, halved, or quartered material has the disadvantage of longer cooking time and additional labor of size grading. It has an advantage over the use of slices in that better retention of water-soluble material is obtained, since less surface area is exposed to leaching action and oxidation. When potatoes were sliced three-sixteenths of an inch and blanched in steam for 4 minutes, the loss of ascorbic acid was 68.4 percent; when they were quartered and blanched in steam for 20 minutes the loss of ascorbic acid was 23.5 percent. The cut product intended for ricing can be precooked by means of flowing steam, boiling water, or steam under pressure in a retort. Cooking in flowing steam or by steam under pressure is preferred over the water cooking method since water cooking may lead to excessive loss of water-soluble nutritive materials from the product.

Cooking in flowing steam can be accomplished by one of two methods. The first method consists of spreading the material on trays and placing them in a cabinet or a retort into which live steam is allowed to escape for the time required to thoroughly cook the material. The second method consists of passing the prepared material on a belt through a continuous steam blancher, as described for slices or cubes. In this case, however, the retention time may be somewhat longer than required in ordinary blanching in order to effect thorough cooking. For the cooking of whole, halved, or quartered pieces the cabinet or retort method is the most satisfactory, since the retention time is so great as to make it impossible to handle a large volume of material by the continuous method. Cooking with steam under pressure has the advantage of shortening the retention time for thorough cooking, and is especially useful for cooking whole, halved, or quartered material.

Regardless of the method, the cooking time will vary with a number of factors, such as type of vegetable, variety, maturity, and quality, size of pieces, rate of loading, temperature of the cooker, and uniformity of heat distribution in the cooker. Because of these factors each operator must determine the cooking time by trial, the criterion of adequate cooking being the production of a product readily passing through the ricer free of lumpy material. For the cooking of quartered material in flowing steam the retention time may range from 20 to 40 minutes.

BLANCHING

The terms "blanching" and "scalding," as used in the canning, freezing, and dehydration industries, refer to the practice of heating the prepared raw food product, in live steam or boiling water, for a short period prior to the principal preservation treatment. In dehydration, blanching is practiced for two primary reasons: (1) To prevent or check the development of undesirable colors, flavors, odors, and the loss of vitamins during dehydration and storage, and (2) to obtain a finished product that will rehydrate and cook rapidly and yield a cooked product of desirable texture. In addition, blanching destroys many of the microorganisms in the raw products. Fruits are not blanched, although blanching has been suggested for certain cut fruits. Recommended blanching treatment varies with the vegetable; specific recommendations are presented in a later division of this publication.

The importance of blanching as a means of preserving quality is exemplified by potatoes; if not blanched, they will come from the dehydrator in a discolored condition and after a few days of storage will develop rancid odor and flavor. Similarly unblanched dehydrated carrots lose their characteristic color during storage and soon develop a stale odor and flavor. With green snap beans blanching influences the time required for reconstitution and cooking and also the quality of the cooked product. In one experiment conducted at the Western Regional Research Laboratory it was observed that unblanched dehydrated snap beans absorbed about 1.1 grams of water per gram of dry product on soaking in water for 4 hours, as compared with 1.9 grams for material that had been blanched in steam for 2 minutes, and 2.3 grams for material blanched in steam 10 minutes. On rehydration, the difference between certain blanched and unblanched materials is apparent. The unblanched material tends to remain shriveled and tough in texture, whereas blanched material becomes plump and tender.

Adequacy of Blanching as Measured by Tests for Enzyme Activity

It is generally believed that at least a part of the deterioration in quality that occurs in unblanched dehydrated vegetables is the result of enzyme action. Enzymes are substances present in all living cells, and their function is to accelerate chemical reactions in the cell. In the absence of these accelerators, life would not be possible, since the chemical reactions necessary to life would proceed too slowly or possibly not take place at all. It may be assumed, then, that if the enzymes are inactivated or destroyed, some of the chemical reactions leading to the development of undesirable qualities in dehydrated vegetables will be retarded or prevented. Since enzymes can be destroyed by heat, it has been assumed that the tendency of blanched dehydrated vegetables toward longer storage life than unblanched is due, at least in part, to the inactivation or destruction of the enzymes as the result of blanching.

On the basis of this assumption, tests for the presence or absence of certain enzymes have been adopted as criteria of the adequacy of blanching in dehydrated vegetables. Unfortunately, existing information does not enable one to tell which enzymes may be involved in the quality changes that occur in unblanched dehydrated vegetables during storage. Accordingly, one of the most heat-stable enzyme systems (peroxidase) with some exceptions has been chosen as the test enzyme, on the assumption that if this system is destroyed it is highly probable that the enzymes that may actually be involved will likewise be destroyed by the blanching treatment. However, it is known that the long blanch required to destroy the peroxidase system in some products, as indicated by the interpretation of the tests employed at present, is in excess of that actually required for the preservation of quality in the dried products.

This is an unfortunate situation, since it may lead to the excessive loss of nutritive values from the products as the result of overblanching. Nevertheless, since adequate information concerning the relation between peroxidase activity and the keeping quality of dehydrated vegetables is not available, it is necessary to adhere to the present test as an indication of adequate blanching in order to be on the safe side. There are cases in which judgment must be exercised, since in some products, even under ideal blanching conditions, it seems impossible to inactivate the peroxidase system, as now interpreted, within a blanching time compatible with practical operating conditions. Rutabagas are an example, for it has been demonstrated that inactivation of the peroxidase system, as indicated by the benzidine test, requires over 30 minutes of blanching. (See section on "Determination of Adequacy of Blanching," p. 147.)

Methods of Blanching

There are three common methods of blanching: Steam blanching, water blanching, and series blanching. Steam blanching consists in subjecting the prepared product in suitable equipment to the temperature of live steam (212° F. at sea level) or to higher temperatures obtained with steam under pressure. Water blanching in its essential features consists of dipping or passing the prepared product through boiling water. Series blanching is a modification of water blanching in that the soluble solids leached from the products during blanching in water are allowed to accumulate to a certain concentration in the blanching water. This concentration (4 percent has been recommended) is then maintained by the gradual introduction of fresh water and removal of spent water.

Each method offers advantages and disadvantages. With the steam blanch it may be more difficult to obtain a uniformly blanched product than with the water blanch. It is generally conceded that water blanching results in a greater loss of water-soluble materials, such as sugar, minerals, and certain vitamins, than does steam blanching. This appears to be true from comparisons made on the same blanching-time basis (table 6). However, the time required to blanch a given quantity of material adequately in water may prove to be less, under certain operating conditions, than that required to obtain the same degree of blanching in steam, in which case the difference between steam blanching and water blanching with respect to loss of water-soluble materials might not be so great. Series blanching has been recommended by British investigators on the grounds that there is less loss of soluble materials from the blanched material. Investigations of the Western Regional Research Laboratory tend to indicate, however, that losses due to series blanching may be less than those encountered in ordinary water blanching, but not necessarily less than with steam blanching.

TABLE 6.—*Effects of water blanching and steam blanching on losses of vitamin C, sugar, and protein from dehydrated vegetables*

Vegetable	3-minute blanch in—	Vitamin C lost [1]	Sugar lost [2]	Protein lost [2]
		Percent	*Percent*	*Percent*
Peas	Water	49.0	22.6	22.1
	Steam	28.0	17.5	12.2
Carrots	Water	38.0	12.7	18.5
	Steam	20.0	18.5	4.5
Beans	Water	46.0	7.5	0
	Steam	36.0	3.3	0
Brussels sprouts	Water	32.0		
	Steam	11.0		

[1] Data from Adam, Horner, and Stanworth (*1*). The carrots are reported as diced and the beans as sliced and green.

[2] Data from Horner (*21*).

Very largely because of differences with regard to loss of soluble materials, steam blanching is generally recommended. In fact, Government specifications for most dehydrated vegetables require that the product be steam-blanched.

It is not possible to state accurately the blanching times required for different products, since the time is dependent upon a large number of factors that must be controlled. Among the factors that may influence the blanching time are the following: (1) Size of pieces. Since the product should reach a temperature of at least 190° F. in the center of each piece, it is obvious that the larger the piece, the longer will be the time required to reach this temperature. (2) Depth to which the material is loaded on the blanching trays or belt or amount of material loaded into blancher. It is obvious that the greater the depth of the load, or amount of load, the longer will be the time required for penetration of heat to the center. (3) Uniformity of heat distribution in the blancher. If there are pockets or areas in the blancher in which the temperature is low, a longer blanch will be required to compensate for the low temperatures. (4) Ability of the blancher to maintain a high temperature. If the temperature should drop for any reason, it is obvious that a longer blanch will be required to obtain the same degree of blanch had the temperature not dropped. (5) Characteristics of the raw material, such as variety and maturity of the product.

An additional factor that may influence the blanching time is altitude. This factor applies to both steam and water blanchers operated at atmospheric pressure in those cases where the blanching temperature is specified as that of live steam and boiling water. In general, the greater the altitude the lower will be the temperature that can be maintained, and consequently the longer will be the blanching time. Variations of as much as a degree or two may occur as a result of day-to-day changes in barometric pressure. The following tabulation shows the effect of altitude on the average boiling point of water.

Altitude (feet)	*Boiling point of water (° F.)*
0	212
1,000	210
2,000	208
3,100	206
4.100	204
5,200	202
6,300	200
7,400	197
8,500	196
9,000	195

Since blanching is an essential part of the dehydration process, and since the purchase of finished product by the Government is partially dependent upon adequacy of blanching, the processor of dehydrated vegetables must maintain careful control over the blanching operation. This means that he must be certain that the blancher is designed to insure uniform heat distribution throughout. He should be certain that his steam supply is adequate to maintain a constant, uniform temperature, and must provide for uniform loading and spreading of the material. The blancher should be provided with thermometers at various points so that frequent checks can be made on the maintenance of temperature and uniformity of heat distribution. As it comes from the blancher the product should be tested at frequent intervals for adequate blanching by the use of enzyme tests. If a positive test is obtained, steps should be taken immediately to discover the cause and remedy it. Under ordinary blanching conditions, where the operation is carried out under atmospheric pressure, the operator should strive to maintain the temperature in the blancher as close to 212° F. as possible.

Vegetable Blanchers

The dip method or tank blanching requires a steam-heated water vessel. If the unit is used for batch blanching, the produce is placed in perforated metal baskets and held submerged in hot water until all of the product has been raised in temperature above 190° F. If dip blanching is to be continuous, the blancher is equipped with a double draper belt similar to that shown in figure 17. The upper belt is used to hold the product submerged in the tank during the blanching process. Another method of adapting the tank blancher for continuous processing is to provide an endless chain fitted with hooks to carry metal mesh baskets through the bath (fig. 18). Naturally. the retention time will depend upon the speed of the belts and the length of the tank.

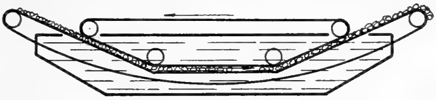

FIGURE 17.—Dip blancher equipped with double draper belt.

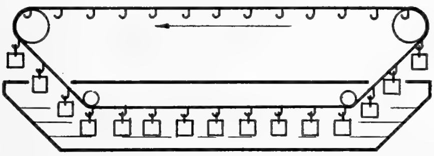

FIGURE 18.—Dip blancher equipped with baskets.

Atmospheric steam blanching can be either a batch or continuous process. The method consists essentially of exposing cut vegetables to steam in a booth or chamber.

The batch-type steam blancher is usually a chamber in which trays of cut vegetables are placed. After the door is closed, steam is admitted at various points along the box so as to fill the chamber completely, thus exposing the product to steam in motion. The resulting washing action by the steam increases the rate of heat transfer from the steam to the product. Entrapped air, being heavier than steam, is discharged through ports located at or near the bottom of the cabinet. Without these ports, air locks may form, which will prevent effective and uniform blanching.

The continuous atmospheric blancher usually consists of a tunnel or large cabinet containing a wire or perforated-plate belt on which the product is loaded. The tunnel is fitted with steam sprays both above and below the belt throughout its entire length. Reinforcing the steam supply at the initial phases of the blanching cycle is sometimes practiced, since the additional steam is useful in rapidly heating up the product to the blanching temperature.

A modification of this form of blancher consists of a similar tunnel fitted with conveyor chains upon which product-laden trays are placed and conveyed through the tunnel (fig. 3). Usually the same trays are used for both drying and blanching. This type of blancher is particularly suitable for blanching cabbage and other leafy vegetables which cannot be easily handled, once blanched. Inasmuch as tray loading in this case is determined by drying rather than blanching limitations, blanchers of this type must be of considerably greater proportions than simple belt blanchers of equivalent capacity. The repeated exposure of wood trays to blanching will result in rapid deterioration. Trays that have absorbed moisture during the blanching operation naturally increase the drying load.

It is desirable that the center or active section of all tunnel blanchers be located at a higher elevation than either the entrance or discharge ends so as to form a heat lock. Heat lock is caused by the difference in density between steam and air at ordinary temperatures; thus the steam is trapped in the upper portion of the blancher (fig. 19). It is desirable to minimize the clearance between the tunnel walls and the belt so that all of the steam admitted to the chamber comes into intimate contact with the product being blanched.

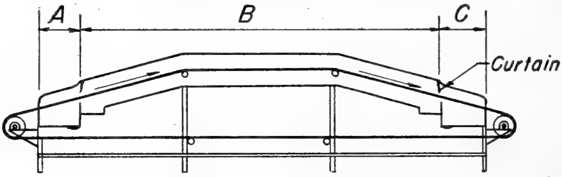

FIGURE 19.—Hump-back blancher showing heat lock.

It is important that all air be kept out of a blancher. To prevent suction of air into the blancher, steam jets should be positioned so as to neutralize the kinetic energy of the jets. This is accomplished by dividing the branch lines into pairs and drilling the steam orifices so that the jets oppose each other.

If steam is allowed to impinge directly on the product, furrows will be cut in the bed, thereby increasing the depth of the bed between furrows. This will retard the rate of blanching, inasmuch as blanching can be considered complete only when the innermost product in the center of the bed is heated up to or above 190° F.

Stacks connected directly to the blancher either at the ends or at the midsection are undesirable. They serve no useful purpose and are in fact detrimental to the blanching process, because live steam is induced to escape. Unattached hoods located at the two ends are desirable to take away unavoidable steam leakage. Some leakage of steam is necessary, however, to insure a full chest of air-free steam.

If water-wash or sulfite-spray sections are provided either before or after the blancher, these should not be constructed so as to cause a draft in the blancher. A satisfactory practice is to eliminate the tunnel cover over the water-wash or sulfite-spray sections. A heavy canvas curtain should be provided at both ends of the blanching section so as to minimize leakage.

Spreading the product on the blanching belt or trays can be accomplished manually or mechanically. For mechanical spreading, use is made of revolving brushes or drums, stationary bars (straight, angular, or curved), or vibrators and shakers. At least two additional procedures are in common use. The material discharged from the cutter may pass into a water flume which empties on the front end of the blancher belt. The water drains through the belt into a sump, leaving the cut material in a uniform layer on the blancher. Another method uses the momentum of the vegetable pieces as they come from the cutter. The discharge spout is removed and replaced by a suitably shaped deflector plate. Proper use of this method on diced vegetables gives a satisfactory spread over a width of three feet or more.

The multiple-belt blancher, as its name implies, comprises a number of belts. The product is dropped from one belt to the other as it progresses through the blancher (fig. 20). It has the advantage of being considerably more compact than the ordinary continuous blancher. Designing such a blancher, however, is a difficult task and requires considerable mechanical skill. Because of multiplicity of parts and the alternate stresses produced in the side walls of the unit, it cannot be readily constructed of wood.

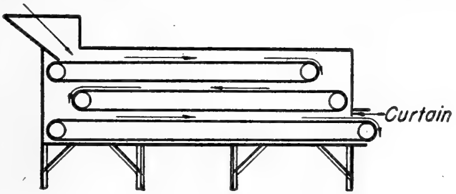

FIGURE 20.—Multiple-belt blancher.

Retort blanching requires a means of subjecting cut vegetables to steam above atmospheric pressure. This method is quick and positive; however, the equipment is costly and, being essentially a batch process, must be supplied in duplicate so as to produce a steady flow of product. The labor required also may limit its use in dehydration. Improvement in product quality resulting from this process is probably negligible and the method cannot be justified unless retorts are available and other equipment cannot be procured.

Summary of blanchers.—Of the various types of blanchers now employed in the dehydration industry, the simplest and most commonly used is the belt blancher. If this unit is modified for use as a continuous-tray blancher, the effective blanching area must be greatly enlarged to achieve the same blanching capacity (fig. 21). This is necessitated by the lighter tray loading as compared to belt loading. The multibelt-continuous blancher is not suitable for use with cabbage or other products that are difficult to handle after blanching. It is compact, but more difficult to build than the continuous-belt blancher.

FIGURE 21.—Steam-blanched diced carrots being loaded directly from the blancher on drying trays.

The tank-dip blancher is the simplest form of unit, is generally acceptable only for moderate-scale operation, and is not conducive to highest quality of product.

SULFURING VEGETABLES

The treatment of certain vegetables with sulfite solutions prior to dehydration has been used and recommended considerably in England, Australia, and Canada during the past 2 years, but has not been applied commercially in the United States until recently. It has been adopted with some reluctance in the United States because of a general antipathy toward sulfur dioxide in any form as a food preservative. However, its accepted use in dried fruits and the definite improvement in retention of palatability, color, and ascorbic acid through processing and storage of dehydrated cabbage treated with a sulfite solution, ultimately forced its acceptance. Recent Government purchase specifications for dehydrated cabbage provide that the product shall be so sulfited that it contains sulfur dioxide within the limits of 750 to 1,500 parts per million.

Sulfiting of white potatoes and carrots has been under consideration, but up to the present specifications have not been issued in which tolerances for sulfur dioxide have been included. The sulfiting of white potatoes does not present unqualified advantages. From the standpoint of acceptable palatability they tolerate substantially less sulfite (perhaps not over 500 p. p. m. as SO_2) without exhibiting an undesirable sulfur flavor in the reconstituted product. Moreover, the B vitamins are unstable in the presence of sulfites, and potatoes lose these vitamins when so treated. Application of sulfite to some potatoes may result in better color as the product comes from the dehydrator and also better retention of quality through storage under adverse conditions. Carrots will probably respond more favorably to sulfite treatment than potatoes, from the standpoint of improved storage characteristics, and will probably tolerate a higher content of sulfur dioxide without undesirable sulfite flavor.

Apart from the beneficial effects that sulfiting offers in the retention of quality, it has made possible the use of higher finishing temperatures in dehydration and consequently shorter drying times. Particularly with cabbage, finishing temperatures 10° to 15° F. higher can be employed safely without scorching, as compared with unsulfited cabbage. This has reduced the drying time as much as one-third in some cases. The effect is also observed with onions, potatoes, and carrots.

It is possible to accomplish the sulfuring by any one of several methods. In England where blanching is done by immersion in hot water, it is relatively easy to incorporate the sulfiting treatment by merely adding sulfite salts to the blanching bath and maintaining the desired concentration by addition of salts at fairly frequent intervals. The Canadians also have recommended the immersion procedure and the Australians and New Zealanders have experimented both with dipping and with application by spraying the trayed product. In the United States blanching is done almost exclusively in continuous-belt steam blanchers or in cabinet or pressure retort units, also with steam. Application of sulfite by any dipping technique thus requires the addition of another operation to a processing sequence already firmly established. Since by far the greatest number of blanchers used in this country are of the continuous-belt type, efforts were first directed to the development of a spraying procedure which could be made an integral part of the blanching operation and equipment. This has been successfully accomplished with cabbage and the method has been used in the production of more than a half million pounds of dehydrated sulfited cabbage up to the present time (1944).

The method involves application of a sulfite solution by means of a spray on the cabbage as it is conveyed through the steam blancher. Application to the raw shredded cabbage before it enters the blancher has not proved desirable because of relatively poor absorption of sulfite. Undesirably high concentration of sulfite salts must be used in the solution if enough uptake to give 750–1,500 p. p. m. in the dried product is to be achieved. On the other hand application to the blanched product as it emerges from the blancher will result in very good absorption and will permit the use of relatively dilute solutions. This method has a disadvantage in that excess solution will continue to drain from the trays as they are stacked and may lead to variations in sulfite content between the upper and lower trays and, with wood slat trays, to staining unless the trays are new or very carefully cleaned.

It appears that objections to spraying before or after blanching can be overcome by application during the blanching process. In this way the partially blanched cabbage absorbs the sulfite efficiently and the product is discharged from the blancher with an essentially dry surface, so that no draining from one tray to the next lower results.

Blanchers and raw stocks of cabbage vary so much that it is impossible to give a detailed procedure that can be applied under all conditions with equal effectiveness. In general the spray should be located at a point one-third to one-half the length of the blancher from the entrance end. In long blanchers (50 feet or more) best results have been obtained by installing the spray at one-third of the way. In a 20-foot blancher best results have been obtained by placing the spray at the midpoint. The best location is apparently critical and should be determined by trial.

In order to obtain good coverage and uniform results in spite of unavoidable variations in tray loadings, it is necessary to apply the spray at a rate that will result in some run-off. A rate of 5 to 10 gallons of solution per 100 pounds of trayed cabbage is recommended. Various types of sprays can be used, such as single or multiple (3 or 4) pipes extending across the blancher at right angles to the direction of belt travel and a few inches above the cabbage, drilled with $\frac{3}{32}$- to $\frac{5}{32}$-inch holes about 1 inch apart. Still another type consists of a single transverse pipe with the holes so drilled that the jets play against the roof of the blancher and the solution is splattered out rather uniformly over the product. At present it is not known which type is most effective.

The sulfite solution is conveniently supplied to the sprays from two wood or concrete tanks of such size that each will carry enough for an 8-hour shift. On this basis 3,500-gallon tanks should easily supply a plant with 50 tons of daily capacity. The second tank is used in making up fresh solution to desired strength while the first is in use. Each tank should be equipped with a mixer that will give vigorous stirring without beating air into the solution. The tanks should be set at a level that will supply a minimum head of 12 feet, or if this is not practicable a pressure pump must be provided to deliver the solution to the sprays.

Control of the sulfite content of the dehydrated product is effected by adjustment of the concentration of the sulfite in solution. For cabbage the required concentration will usually lie within the range of 0.15 to 0.30 percent, calculated in terms of SO_2, depending upon cabbage variety, blancher, and dehydrator conditions and perhaps other variables. Either the normal sodium sulfite or mixtures with sodium metabisulfite can be used. At present the influence of pH of the applied sulfite solution on product quality is inadequately understood. From the corrosion standpoint it is advisable to use a predominant amount of the normal salt to keep the pH at 7 or above. Moreover, with green varieties of cabbage better color results when the more alkaline solutions are used. However, alkaline sulfite solutions are more readily oxidized by air than are those at lower pH, so that important amounts may be converted to inactive sulfate. In the absence of complete information it seems best to use a mixture of the two salts which will give a solution in the range of pH 7 to 8. A convenient proportion consists of 3 parts by weight of sodium sulfite to 1 part of the metabisulfite, which yields a solution of approximately pH 7.2. If desired the cheaper metabisulfite can be used and the correct pH achieved by addition of soda ash.

Hard waters cause precipitation of the highly insoluble calcium sulfite, which results in a milky appearance of the solution and upon accumulation may cause clogging of spray jets. This precipitation may be effectively inhibited by dissolving sodium hexametaphosphate (Calgon) in the water to give a concentration of 5 p. p. m. prior to addition of the sulfite salts. The sulfite salts dissolve somewhat more slowly in the presence of the phosphate and a large excess is to be avoided because of its potentially unfavorable tenderizing action on the cabbage.

Reasonable caution should be exercised in handling sulfite solutions to avoid contamination with metals such as iron and copper, since these catalyze the oxidative conversion to inactive sulfate. Contact with air should be minimized, especially with solutions of high pH. If a solution is held more than a few hours it should be mixed, sampled, and rechecked for sulfite content and refortified, if necessary, before use.

Corrosion of metal trays will not be serious, provided solutions of pH 7 or higher are used. Tinned trays must be kept well coated; otherwise cabbage coming in contact with exposed iron will be seriously stained as a result of the relative positions of tin and iron in the electrochemical series. Galvanized-iron trays are less likely to cause staining of the product, since the zinc is more active than the iron and hence soluble iron does not reach the cabbage. Cloths over the tray screens have been tried to avoid staining and to facilitate removal of the dried product without excessive fragmentation. Unfortunately, although the cloths are very helpful in detraying operations, they do not work satisfactorily when sulfite is used. Metal trays can be treated with a light coat of mineral oil to avoid sticking of the dried cabbage.

In plants equipped with cabinet blanchers sulfiting can be carried out by dipping baskets of the raw shredded material in a tank of sulfite solution. If dipped cold it is necessary to use a solution of 0.5 percent as SO_2 or greater to obtain the desired uptake. The cabbage should remain immersed a minimum of 15 seconds, should be removed and drained another 15 seconds, and then dipped in or sprayed with fresh water for 5 seconds. Then it is spread on trays and blanched in the usual way. Varieties of cabbage may be expected to show considerable variation in absorption of sulfite from cold solutions; therefore trials must be made with different sulfite concentrations on each new lot of cabbage. Perhaps a more satisfactory procedure is to dip the raw cabbage in a hot (180°–190° F.) sulfite solution for 5 seconds, drain briefly, dip momentarily in fresh water, and then spread on the trays and blanch. Lower concentrations of sulfite can be used when the solution is applied hot—0.2 to 0.4 percent as SO_2 ordinarily being adequate.

Dipping of cabbage after blanching is not satisfoctory because of the difficulty of traying the softened product. It is possible to apply the sulfite as a spray, followed by a fresh-water spray on trayed blanched material. This procedure, however, is not wholy satisfactory and cannot be recommended for cabbage because of draining complications.

Laboratory and pilot-plant experiments have demonstrated that both potatoes and carrots can be successfully treated by application of sulfite solutions as a spray during blanching in much the same manner as for cabbage. If future specifications require sulfiting of these commodities, the required solution concentrations will of course be influenced by the specified content of sulfite in the dry product.

PRINCIPLES INVOLVED IN THE DRYING PROCESS

The drying operation is a major step in the manufacture of dehydrated foods and may be defined as controlled evaporation of nearly all of the water present in the fresh product. The evaporation of water under these conditions is, however, a complex process, and its principles are sufficiently important to justify discussion here.

The Vaporization of Water

If a container is partly filled with water at a temperature of 100° F. and the air is removed from the space above the water by means of a vacuum pump, and then the container is tightly closed, a sensitive manometer connected to the vapor space will indicate the gradual development of a pressure within the "empty" space. If the temperature of the water is maintained at 100° this pressure will increase up to 1.93 inches of mercury. The higher the temperature of the water, the higher the pressure of its vapor will be; at 212° the vapor pressure of water is 29.92 inches of mercury—the same as average barometric pressure at sea level. Table 7 presents values for vapor pressure of water over a range of temperatures (*39*, p. 960).

Suppose that the container of water at 100° F. is left open to the air, so that the space above the water must remain at atmospheric pressure—say 30 inches of mercury. Water evaporates from the surface of the liquid, and the water vapor pushes out some of the air, since the pressure cannot rise above 30 inches. When the system comes to equilibrium, the space above the water will be filled with a mixture of air and water vapor. Each of these components is contributing a part of the total pressure of 30 inches; at a temperature of 100° F. the water vapor is contributing 1.93 inches, the air 28.07 inches.

These two quantities are termed "partial pressures." Before the system reached equilibrium, the space was not yet saturated with water vapor. It became saturated when the partial pressure of water vapor in the space rose to equality with the vapor pressure of water at that temperature.

The fluid content of the cells of vegetables and fruits does not consist of pure water, but is a complex solution of salts, sugars, and other substances. The vapor pressure of such a solution is always somewhat lower at any given temperature than the vapor pressure of pure water; the more concentrated the solution, the greater the difference. The liquid in a fresh vegetable is dilute, but as dehydration progresses the liquid left behind becomes more and more concentrated and its vapor pressure becomes lower and lower. This is one of the major reasons why the final stage of drying a fruit or vegetable proceeds so much more slowly than the initial stages.

Returning to the example of evaporation at 100° F., we find that as evaporation proceeds the liquid cools down below 100° unless additional heat is supplied. Actually, 1,037 B. t. u.[3] would have to be supplied to the liquid at 100° F. for every pound of water evaporated.

TABLE 7.—*Properties of water vapor and air*

Temperature (° F.)	Vapor pressure of water	Latent heat of vaporization	Absolute humidity at saturation [1]	Specific volume [1]	
				Dry air	Saturated air
	Inches of mercury	*B. t. u./lb.*	*Lb. vapor/lb. dry air*	*Cu. ft./lb.*	*Cu. ft./lb. dry air*
0	0.0375	1,094	0.00079	11.58	11.59
10	.063	1,088	.00132	11.83	11.86
20	.103	1,083	.00216	12.09	12.13
30	.165	1,077	.00347	12.34	12.41
40	.248	1,071	.0052	12.59	12.70
50	.362	1,066	.0077	12.84	13.00
60	.52	1,060	.0111	13.10	13.33
70	.74	1,054	.0158	13.35	13.69
80	1.03	1,049	.0223	13.60	14.09
90	1.42	1,043	.0312	13.86	14.55
100	1.93	1,037	.0432	14.11	15.08
110	2.59	1,032	.0595	14.36	15.72
120	3.44	1,026	.0815	14.62	16.52
130	4.52	1,020	.1114	14.88	17.53
140	5.88	1,014	.1532	15.13	18.84
150	7.57	1.008	.2122	15.39	20.60
160	9.65	1,002	.2987	15.64	23.09
170	12.20	996	.432	15.90	26.84
180	15.29	990	.658	16.16	33.04
190	19.01	984	1.098	16.41	45.00
200	23.46	978	2.30	16.67	77.2
210	28.75	972	13.4	16.92	382
212	29.92	970		16.97	
220	35.0	965		17.1	
230	42.3	959		17.4	
240	50.8	952		17.6	
250	60.7	945		17.9	
260	72.1	938		18.1	
270	85.2	931		18.4	
280	100.1	924		18.6	
290	117.2	917		18.9	
300	136.4	910		19.1	

[1] Barometric pressure, 29.92 inches of mercury.

This quantity of heat that is absorbed when a pound of water vaporizes is known as the latent heat of vaporization. It varies slightly with temperature (see table 7), but under the usual conditions of dehydration it is approximately 980 to 1,050 B. t. u. per pound of water evaporated. A considerable proportion of the heat supplied to a dehydrator goes to furnish this latent heat.

Properties of Air and Water Vapor

According to the definition given above, air is "saturated" with water vapor when the partial pressure of the vapor in it equals the vapor pressure of water at that temperature. Saturated air is just on the point of becoming foggy; if there is actual fog, the saturated air is carrying an additional quantity of water in the form of liquid droplets.

The "dew point" of any given mixture of water vapor and dry air is the temperature at which it would become saturated with water

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[3] A British thermal unit is the quantity of heat required to raise 1 pound of water 1° F. in temperature.

vapor if it were cooled without change in proportion of vapor and air. Then if the mixture is already saturated, its dew point coincides with its temperature, while if it is less than saturated, its dew point is lower than its temperature. If air is saturated at any given temperature and then heated to a higher temperature without change in proportion of water vapor, its dew point remains unchanged.

The term "humidity" is used for any of several different ways of expressing the amount of water vapor carried by air.

The expression "relative humidity" is most commonly used in meteorological work and air conditioning for human comfort, and is simply the following ratio: Percent relative humidity $=100\times\frac{\text{Partial pressure of water vapor in air}}{\text{Vapor pressure of water at same temperature}}$. Then saturated air has a relative humidity of 100 percent, and air containing no water vapor has a relative humidity of 0 percent. At temperatures above the boiling point of water the relative humidity is always less than 100 percent, even for pure water vapor unmixed with air.

In work with dehydrators there are many advantages in the use of the expression "absolute humidity," which is defined as follows: Absolute humidity=pounds (or grains) of water vapor per pound of dry air (1 pound equals 7,000 grains).

Whenever absolute humidity is referred to in this manual pounds of water vapor per pound of dry air should be understood. The convenience of working with absolute humidities arises from the fact that they are expressed on a weight basis. A pound of dry air entering a dehydrator, for example, still weighs just a pound at any other point in the dehydrator, no matter what changes in temperature or pressure may have taken place, or how much water vapor may have been added to it.

The absolute humidity of completely dry air is, of course, 0 pound per pound. The absolute humidity of saturated air rises as the temperature rises, and becomes infinite at and above the boiling point of water. A column in table 7 gives its values at a barometric pressure of 29.92 inches and at temperatures below 212° F. The definition for percent absolute humidity is as follows: Percent absolute humidity= $100\times\frac{\text{Absolute humidity, pounds vapor per pound dry air}}{\text{Absolute humidity saturated air, pounds vapor per pound dry air}}$. Note that percent absolute humidity is different numerically from percent relative humidity; see the following paragraph for a formula for converting one to the other. Percent absolute humidity, like the absolute humidity of saturated air, loses its significance at air temperatures above the boiling point of water.

Any of the various ways of expressing humidity may be converted into any of the others through the use of one or more of the following formulas. Some of these formulas are not exact, particularly at the higher humidities, but their accuracy is sufficient for practical purposes.

$$a=\frac{0.625p}{B-p}$$

$$a_s=\frac{0.625P_s}{B-P_s}$$

$$a=\frac{0.625P_s\text{ (percent }RH)}{100B-P_s\text{ (percent }RH)}=\frac{0.625P_s\text{ (percent }AH)}{100(B-P_s)}$$

$$\text{(percent }AH)=100\frac{a}{a_s}=\frac{100p(B-P_s)}{P_s(B-p)}=\frac{100a(B-P_s)}{0.625P_s}=$$

$$\frac{100\text{ (percent }RH)(B-P_s)}{100B-P_s\text{ (percent }RH)}=\frac{\text{(percent }RH)(a+0.625)-100a}{0.625}$$

$$\text{(percent }RH)=100\frac{p}{P_s}=\text{(percent }AH)\frac{B-p}{B-P_s}=$$

$$\frac{100B}{P_s}\left(\frac{a}{a+0.625}\right)=\frac{100a+0.625\text{ (percent }AH)}{a+0.625}$$

In these formulas, the symbols have the following meanings:

a=absolute humidity, pounds water vapor per pound dry air.
a_s=absolute humidity of saturated air.
B=barometric pressure, inches of mercury; for the standard chart B=29.92 inches.
p=partial pressure of water vapor in the air, inches of mercury; note that p is equal to the vapor pressure of water at the dewpoint of air of the given composition.
P_s=vapor pressure of water at the given temperature, inches of mercury.
(percent AH)=percent absolute humidity.
(percent RH)=percent relative humidity.

The unfortunate multiplicity of terms for expressing the conception of moistness of air is reflected in some confusion in the existing literature on dehydration. The older discussions referred almost entirely to percent relative humidity; the term is still used to some extent, particularly in the analysis of the moisture-vaporproofness of packaging materials. In work on the drying step alone, however, there is little occasion to use the concept of "percent humidity" (either relative or absolute) at all. Dehydrator operation can be as effectively controlled through the use of two temperatures (dry-bulb and wet-bulb) as through the derived term "percent humidity." Dehydrator design does not necessitate the use of "percent humidity" in any form.

Volume of Mixtures of Air and Water Vapor

The volume, in cubic feet, occupied by a pound of any gas, such as air, is known as its specific volume. Air and mixtures of air and water vapor, like other gases, occupy more volume per pound weight at higher temperatures than at lower ones, and at lower barometric pressures than at higher ones. The specific volume of dry air at normal sea-level barometric pressure (29.92 inches of mercury) is shown in table 7. Correction to a different barometric pressure, for example the lower pressures which prevail at higher altitudes, may be accomplished by applying the following rule: **Specific volume varies inversely as the total pressure.**

Example: A dehydrator is to be operated at an elevation of 4,500 feet, where normal barometer is 25.2 inches. What will be the specific volume of dry air at 160° F.?

From table 7, specific volume at 29.92 inches and 160° F.=15.64 cubic feet per pound. At 25.2 inches, specific volume $=15.64\times\frac{29.92}{25.2}=18.56$ cubic feet per pound.

The pressure inside a dehydrator is usually higher or lower than that of the outside air. If this difference in pressure is determined by reading a water manometer, the total pressure can be calculated by converting the manometer reading to inches of mercury (13.6 inches of water=1 inch of mercury) and adding it to, or subtracting it from, the barometric pressure. This is usually only a minor correction.

Since a centrifugal fan, running at constant speed, will deliver approximately the same volume of air per minute regardless of the specific volume of the air, the weight of air circulated per minute will usually be less if the fan is operated at high altitude, for example in Colorado, than if it is operated near sea level. The effect on dehydrator performance may be appreciable. Boiler furnaces which are to be used at high altitudes also must be designed to take account of the increased specific volume of air and of flue gases.

The volume of 1 pound of dry air plus enough water vapor to saturate it is known as the saturated volume. Values of the saturated volume at sea level barometric pressure and various temperatures are given in table 7. At low temperatures so little water vapor is required to saturate air that the saturated volume is only slightly higher than the specific volume of dry air. At higher temperatures the mixture becomes almost pure water vapor, and saturated volume approaches an infinite value.

The equivalent term for unsaturated mixtures of air and water vapor is "humid volume." If the percent absolute humidity of a mixture is known, its humid volume may be calculated from the following formula:

$$\text{Humid volume}=\text{specific volume of dry air}+\frac{\text{percent absolute humidity}}{100}(\text{saturated volume}-\text{specific volume of dry air}).$$

Example: At 160° F., saturated volume=23.1 cubic feet per pound of dry air; specific volume of dry air=15.6 cubic feet per pound. What will be the humid volume at 45 percent absolute humidity?

Humid volume $=15.6+\frac{45}{100}(23.1-15.6)=19.0$ cubic feet per pound of dry air.

The humid volume will have a finite value at temperatures above the boiling point of water, but the foregoing formula does not then apply. The volume can be calculated with reasonable accuracy for any temperature, if the absolutely humidity is known, by using the following formula: Humid volume $=(0.0253+0.0405\times\text{absolute humidity})$ (temperature, °F.,$+460$.)

Example: If a mixture of air and water vapor at a temperature of 220° F. has an absolute humidity of 0.27 pound water vapor per pound dry air, what is the humid volume of the mixture? Humid volume $= (0.0253 + 0.0405 \times 0.27)\ (220 + 460) = 24.6$ cubic feet per pound of dry air.

In rough calculations of the drying capacity of common types of hot-air dehydrators it is often sufficiently accurate to assume that the humid volume of air is 16 cubic feet per pound. This approximation should not be used in calculations where precision is essential.

Specific Heat of Air-Water Vapor Mixtures

The specific heat of any substance is substantially equal to the amount of heat, in B. t. u., required to raise the temperature of 1 pound of it 1° F. The specific heat of dry air in the usual range of dehydrator temperatures is 0.24. That is, 0.24 B. t. u. applied to 1 pound of dry air will raise its temperature 1°.

The humid heat of air containing water vapor is defined as the quantity of heat required to raise the temperature of 1 pound of dry air, plus whatever water vapor accompanies it, 1° F. Since the specific heat of pure water vapor is approximately 0.45, the humid heat may be calculated by using the following formula if the absolute humidity is known: Humid heat $= 0.24 + 0.45 \times$ absolute humidity.

Example: 1,000 pounds per minute of dry air with an absolute humidity of 0.05 pound of moisture per pound of dry air is flowing through a heater. How much heat must be supplied per minute to raise the temperature of the air 150° F.? Humid heat $= 0.24 + (0.45 \times 0.05) = 0.262$. Heat required $= 1{,}000 \times 150 \times 0.262 = 39{,}300$ B. t. u. per minute.

Wet-Bulb Temperature

When a moist object is exposed to a current of air, the evaporation of water from the object cools both the air flowing past it and the object itself. The drier the air, the greater will be the amount of cooling. If the air is saturated with water vapor, no evaporation will take place and no cooling will occur. These facts are the basis for the use of the wet-bulb thermometer for measuring and controlling the humidity of air in a dehydrator. The temperature of the air, as read on an ordinary thermometer, may be distinguished by calling it the "dry-bulb temperature." The difference between dry-bulb temperature and wet-bulb temperature is called the wet-bulb depression. At any given temperature, the greater the wet-bulb depression the drier the air. A wet-bulb depression of 0° F. indicates saturated air. Wet-bulb depressions of as much as 100° are encountered in some commercial dehydrators.

The directions given in this manual for dehydrating various fruits and vegetables are expressed in terms of dry-bulb and wet-bulb temperatures. While these values can be translated into terms of percent relative humidity or percent absolute humidity if desired, nothing important from the operative viewpoint is gained by doing so. Direct use of the temperatures, which are read from the instruments, has the great advantage of simplicity.

Calculations of dehydrator capacity and heat requirement, on the other hand, do require translation of these temperatures at least into terms of absolute humidity. This may be accomplished most easily by means of a humidity chart.

Humidity Charts

Several different forms of humidity charts are in use. Some of them are based primarily on relative humidities; figure 22 is an example.[4] Figure 23 is based on absolute humidities. Both are calculated for a barometric pressure of 29.92 inches.

Example 1. What is the relative humidity of air with a dry-bulb temperature of 160° F. and a wet-bulb temperature of 110° F.? From figure 22, percent relative humidity = 21 percent.

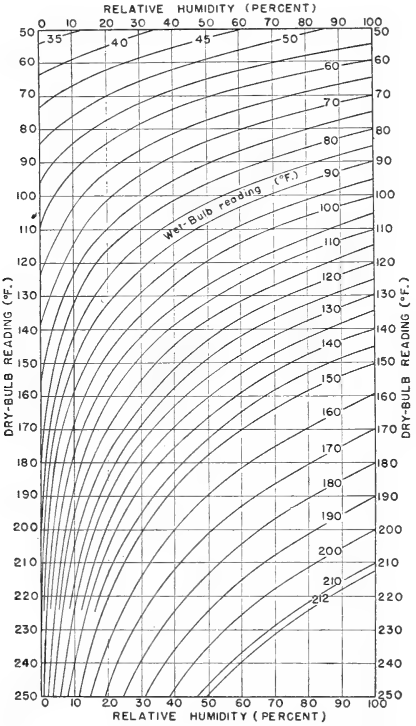

FIGURE 22.—Humidity chart—percent relative humidity.

Example 2. What is the absolute humidity under those same conditions? From figure 23, absolute humidity = 0.0463, and percent absolute humidity = 15.5 percent.

Example 3. What is the dew point of the air under those conditions? The dew point is the temperature at which air of the same absolute humidity would be saturated. From figure 23, the dew point = 102.3° F.

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[4] The fundamental measurements on which humidity charts are based are scanty and to some extent conflicting, except within the usual range of outdoor temperatures and humidities. Discrepancies between different charts are serious at the higher temperatures and humidities characteristic of commercial dehydrators. The Committee on Psychrometry of the American Society of Heating and Ventilating Engineers is now engaged in redetermining the fundamental properties of mixtures of air and water vapor in an effort to arrive at a fully trustworthy humidity chart. The charts given in this manual are based on data by Keenan and Keyes (*24*), and at temperatures below 125° F., on data of the American Society of Heating and Ventilating Engineers (*2*).

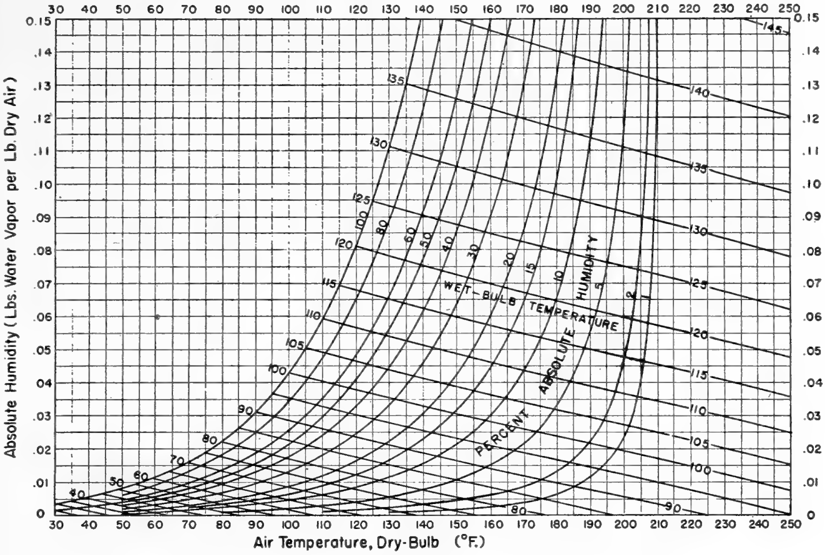

FIGURE 23.—Humidity chart—absolute humidity.

Characteristics of Evaporation from a Moist Solid

Moisture content.—The moisture content of a fruit or vegetable, either fresh or dried, is usually expressed as a percentage by weight. For example, the analysis of a sample of blanched potato strips may be given as 80 percent moisture—that is, in 100 grams of sample there are 80 grams of water and 20 grams of "bone-dry" matter. Calculations of processes in a drier are much simpler, however, if the moisture content is expressed on the "dry basis"; that is, as the ratio of water content to dry matter. In the foregoing example this ratio is 4.0. The convenience of this method arises from the fact that the weight of dry matter remains constant as material progresses through the drier, and provides a constant base for calculation of evaporation. For example, the following important, but somewhat paradoxical, statement can be verified by mental calculation: **Most of the water is evaporated while the material is still very wet.**

Suppose the material consists of carrot strips, in which the original moisture content is 8 pounds of water per pound of dry matter. Then 8 of every 9 pounds loaded on a tray is water, and 1 pound is dry matter. When 7 pounds, or seven-eighths, of the water has been evaporated, 1 pound of water is left with the same 1 pound of dry matter; the moisture content has been reduced only to 50 percent. About 99.3 percent of the total water must be evaporated before the moisture content of the product falls to 5 percent.

If the moisture contents both of the fresh material entering the drier and of the product leaving the drier are known, the drying ratio, or its reciprocal, the drying yield, can be calculated. The formulas may contain either "percent moisture" (wet basis) or moisture content (dry basis):

$$\text{Drying ratio} = \frac{\text{Weight entering drier}}{\text{Weight leaving drier}} = \frac{100-M_f}{100-M_o} = \frac{T_o+1}{T_f+1}$$

where M_o is moisture content (percent) in the fresh product, M_f is the moisture content (percent) in the product leaving the drier, T_o is the moisture content (pounds water per pound bone-dry) in the fresh product, T_f is the moisture content (pounds water per pound bone-dry) in the product leaving the drier.

The drying yield is the reciprocal of the drying ratio. Blanched carrot strips, for example, enter a drier containing 89 percent moisture, and leave it containing 5 percent moisture. Then

$$M_o=89,\ M_f=5,\ T_o=\frac{89}{11}=8.09,\ T_f=\frac{5}{95}=0.053.$$

$$\text{Drying ratio}=\frac{100-5}{100-89}=\frac{8.09+1}{0.053+1}=8.63.$$

$$\text{Drying yield}=\frac{100-89}{100-5}=\frac{0.053+1}{8.09+1}=\frac{1}{8.63}=0.116=11.6\text{ percent.}$$

The drying ratio and drying yield do not express the total shrinkage in weight of product in passing through the plant. The over-all plant ratio, or its reciprocal, the over-all yield, must also take into account the losses of product during preparation and inspection.

The weight of water to be evaporated can be calculated from the following formula:

$$\text{Evaporation}=\frac{T_o-T_f}{T_o+1}=\text{pounds water per pound material entering drier.}$$

From the preceding example, $\frac{8.09-0.053}{8.09+1}=0.884$ pound water evaporated per pound prepared material entering the drier.

Evaporation from the Surface of a Wet Material

When first exposed to a stream of air, cut and blanched pieces of vegetable or fruit act essentially like a fine-grained sponge full of water. The surface moisture evaporates very rapidly.

Evaporation from a water surface has been studied extensively. The observed relations are to a large extent explainable on the assumption that a stagnant film of nearly saturated air persists at the surface. Air flowing past the surface tears away vapor from the film, which is replenished by evaporation from beneath. The more rapid the flow of air, the thinner the film becomes, and the more rapid the transfer of water vapor into the air stream.

During this initial period (and, indeed, during the time that the first half to three-quarters or more of all the moisture in the piece is evaporating) the wet piece acts essentially like the wick of a wet-bulb thermometer, and, if air velocity is reasonably high, the temperature inside the piece stays at or near the wet-bulb temperature of the air.

Removal of Water From Deeper Layers

Evaporation from the surface cannot proceed far before the surface layers of the piece will become drier than those beneath them. The process of moisture diffusion then starts, and this process must continue during all of the remainder of the drying. It is a complex phenomenon that is still imperfectly understood.

The moisture in fruits and vegetables exists as a dilute solution of sugars, salts, proteins, and other organic compounds, held in the closed cells that constitute living tissue. In order to travel from the inside to the surface of a piece, water must be transferred through all of the cell walls which lie between. That kind of transfer takes place quite freely while the cells are still full of liquid. The direction of flow is always from a cell with dilute content to an adjoining one in which the solution is more concentrated. Evaporation of water at the surface concentrates the cell solution there. Water from the deeper layers then diffuses into it. Before very long this process will have caused loss of moisture from all levels of the piece, all the way to the center.

The cell walls tend, in general, to hold back the dissolved substances, while permitting the water to pass freely; the separation is not perfect, however, so that there is some tendency to move a part of the salts and sugars to the surface and deposit them there when the water evaporates. Even though the cell solution is dilute in the fresh vegetable, so large a proportion of the water is removed that the solution must become exceedingly concentrated long before drying is complete. For example, press juice from fresh carrots may contain about 6 percent sugar; when evaporation has reduced the moisture content of a piece of carrot to 10 percent, there is five times as much sugar present as water. Such a solution is a taffy or glass—not a liquid.

As water is lost from a cell an internal tension is set up which pulls the cell walls inward. The cell partially collapses. This process, occurring throughout the piece, is responsible for the shrinkage that takes place during drying. Since the cell walls are relatively thin, the decrease in volume of the piece is approximately equal to the volume of water lost. Some of the tissues, however, may be more rigid than others, or cell collapse may occur in some directions more freely than in others, so that shrinkage is frequently very nonuniform. The piece loses most of its resemblance to the original shape.

At some point during the dehydration the rigidity of cell walls resists further collapse with enough force so that cavities open up within the cell contents, and the shrinkage stresses may loosen the bonds between cells to some extent or even partly separate them. During the final stages of drying it is probable that much of the diffusion of water within the piece is a diffusion of water vapor through open spaces, rather than transfer of liquid water. The concentration of salts and sugars as drying proceeds slows down this process by reducing the vapor pressure of the solution.

Whether the transfer of moisture takes place by liquid or by vapor diffusion, the rate at which water will move from one layer of cells to the next will depend primarily on two factors—first, the difference in concentration of water in the two layers, and second, the temperature. The difference in concentration provides the driving force for diffusion; the greater the difference, the greater the force. Raising the temperature decreases the viscosity of the liquid and increases its diffusion pressure, whether it is liquid or vapor.

The rate at which water can be removed from a thick piece of vegetable after surface moisture has been evaporated will evidently change radically as the drying progresses. At the start, water will diffuse easily from deep layers to the surface. If the surface layer tends to become dry, diffusion into it from below will speed up because of the increased difference in concentration. So long as the surface remains moist, the temperature of the piece will remain at or near the wet-bulb temperature of the air. The piece shrinks in volume, but since water diffusing from the center must still traverse the same number of cell walls, the resistance to its flow will not decrease; indeed, it may well increase because of a fall in the permeability of the cell walls as they dry out. At the same time the diffusion pressure of the liquid will fall as it becomes more concentrated. As more and more water is lost, the possible difference in moisture concentration between successive layers of cells decreases. The result of all these changes is that the rate of evaporation from the piece falls off continuously as drying proceeds. At some point the evaporative cooling becomes insufficient to hold the temperature of the piece down to the wet-bulb temperature of the air, and the temperature gradually rises approximately to the dry-bulb air temperature.

Experimental measurement of the temperature at the center of carrot slices during dehydration under different conditions indicated that the transition from wet-bulb temperature to dry-bulb temperature occurred generally within the range of moisture contents of about 65 percent ($T=2$) to 33 percent ($T=0.50$), i. e., after about three-fourths of all the water had been evaporated. Data from a typical experimental run are shown in figure 24.

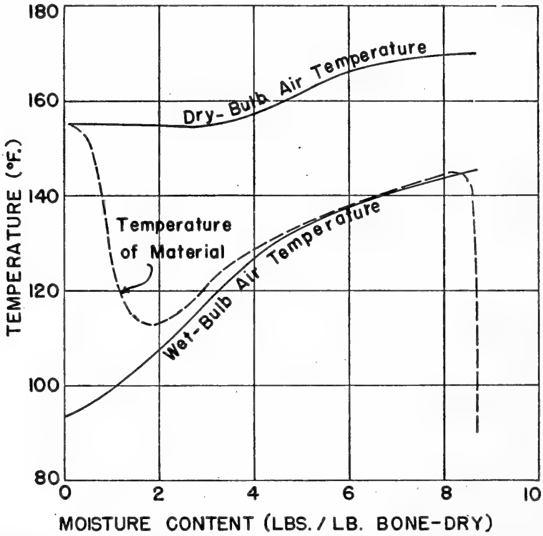

FIGURE 24.—Relation of temperature of material to dry-bulb and wet-bulb air temperatures. Carrot slices three-sixteenths inch thick.

Effect of Thickness of Piece

Increasing the thickness of cut pieces of vegetable slows down the completion of drying very materially. If the rate of drying is expressed as the loss in average moisture content per unit of time, this rate is lower from the very start for thick pieces than for thin ones, but if it is expressed as the loss per unit of surface exposed, per unit of time, it is substantially independent of thickness, at least while the piece is very wet. This indicates that in the early phases of drying the principal resistance to be overcome is that of the vapor film at the surface. As drying proceeds further, the principal resistance shifts to the internal resistance to diffusion of water. It may be regarded as quite probable that the comparative slowness with which heavy fruits can be dried (prunes, peaches, apricots) is traceable at least as much to their thickness as to their high sugar content.

"Case Hardening"

The term "case hardening" was probably borrowed from the older art of kiln-drying lumber. In drying lumber it is essential that the inevitable shrinkage in volume shall take place uniformly and without causing surface checks or cracks. Experience showed that if the drying were hastened too rapidly at first, such cracks invariably resulted. The outer layers, drying more rapidly than the center, shrank down upon a wet and nearly incompressible core. If the difference was excessive, the resulting tension in the outer shell or "case" opened up cracks.

Dehydrators of heavy fruits similarly learned many years ago that they must avoid exposing the moist fruit to too drastic drying conditions. Such exposure, for example, would cause the skins of prunes to check and the fruit would "bleed." It appeared, too, that if the drying were started too fast, the final stage of finishing was likely to be much slower. The fruit acted as though the initial rapid drying formed an impermeable "case" at the surface, through which the remainder of the moisture could hardly diffuse. The reality of the effect is indisputable. Whether it is due to a change in the permeability of surface-cell walls as they become dry, or to the transport of sugars to the surface and their deposit there as a layer of heavy, impermeable "taffy," has not been determined. At any rate, it was observed that this trouble was not experienced when the initial rate of drying was kept moderately low and when internal diffusion of moisture was facilitated by keeping the temperature of the fruit moderately high. Both conditions were obtained at once by keeping the wet-bulb temperature of the air circulating in the fruit dehydrator relatively high.

In dehydrating cut vegetables there is little possibility of the occurrence of surface cracking and bleeding. "Case hardening" would be recognized only by the persistence of a wet center, and drying to the desired low final moisture content would require much longer than would be deemed normal for that vegetable. The term "case hardening" therefore lacks precision of meaning. In fact, it is very difficult to produce a condition that can be clearly recognized as typical "case hardening" in cut pieces of vegetable. Ordinarily, cut vegetables can be dried to completion in the shortest total time when the rate of drying is kept as high as possible at all times.

The maintenance of high wet-bulb temperature does not have the same significance, therefore, in drying vegetables as it has in drying heavy fruits. It does have a function in the control of a dehydrator and in economizing heat, as will be discussed in a later section.

Equilibrium Moisture Content

If a piece of cut vegetable is exposed to a current of air of constant temperature and constant humidity for a long period of time, it will lose weight by evaporation of moisture, rapidly at first, then slower and slower, and at last the weight will remain substantially constant, even if the air circulation is continued for an indefinite length of time. If the piece is then transferred to a current of "bone-dry" air, or to a vacuum oven, it will lose more weight and eventually reach another lower, constant weight. Equilibrium moisture content is a term used to designate the amount of moisture held by a piece in equilibrium with air at a given temperature and humidity. It is the amount of moisture that will give the piece a vapor pressure equal to the partial pressure of water vapor in the surrounding air.

Since vapor pressure in a piece of vegetable becomes lower and lower as the piece approaches dryness, the partial pressure of water vapor in air which is in equilibrium with the piece must also fall. But the partial pressure is proportional to the relative humidity at any given temperature. The higher the relative humidity of the air, therefore, the higher the equilibrium moisture content. If the air is "bone dry," the vegetable also will be "bone dry" at equilibrium.

Equilibriums between the common vegetables and air of varying temperatures and humidities have been determined recently. (See table 9, p. 118.) A way of presenting the data which is especially convenient for use in analyzing dehydrator operation is to plot equilibrium moisture against temperature of air at several different levels of wet-bulb temperature. Figure 25 represents a kind of general average of these equilibriums for the vegetables which are commonly dehydrated. Such an average is sufficiently precise for many dehydrator calculations.

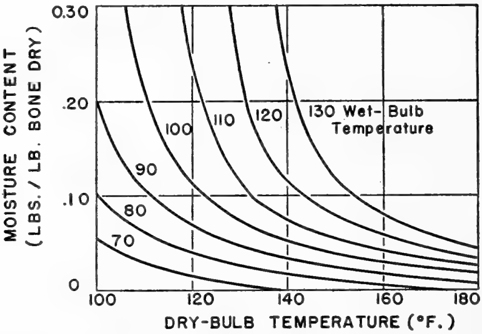

FIGURE 25.—Approximate equilibrium moisture content of common vegetables.

Knowledge of these equilibrium values is important both in dehydrator design and in analyzing the pick-up of moisture into dehydrated vegetables through sheet packaging materials. The finishing end of a dehydrator cannot dry the material to any lower moisture content than the value corresponding to equilibrium with the air at that point. If the finishing air is high in humidity, a very dry product cannot be made. Furthermore, the closer the approach to equilibrium, the slower becomes any further removal of moisture.

If the finishing stage is to proceed at a reasonably high rate, therefore, the humidity of the air must be decidedly lower than that corresponding with equilibrium at the desired final moisture content.

Typical Drying Curves, Constant Drying Conditions

General physical laws and the known properties of air and water vapor make it possible to calculate accurately some important characteristics of a dehydrator. The methods used and some of the results are discussed in a later section. These methods have the strict limitation that they offer no information about the rate at which evaporation will take place; in other words, the time required to bring about a given degree of drying. The foregoing discussion indicates qualitatively the effect of various factors on the rate of drying, but quantitative information can be determined only by experiment.

At least nine separate factors have marked effects upon drying rates (*45*). These are: Variety of fruit or vegetable, shape and size of piece, method of pretreatment (blanching, etc.), method of support in the drier, thickness of layer of moist pieces on the support, manner of exposure to the air stream, air velocity, air temperature, and air humidity. In a vacuum dehydrator still other factors appear. The number of possible combinations of these variables is so enormous that the only practical way to investigate their effects is to conduct a series of controlled experiments; in a group of such experiments all conditions except one are kept constant, and several values of that one will be tried in successive experiments; then in other groups the effects of other variables will similarly be tried one at a time. After careful analysis of a long series of experiments of this kind it becomes possible to estimate with considerable accuracy what the rate of drying will be under any combination of conditions.

Detailed results of experimental work on drying rates are not included here, because such information is principally valuable to dehydrator designers. The following general discussion is introduced for the value it may have in promoting intelligent understanding of what goes on in a dehydrator.

Suppose that the following choice of conditions is made for a single experimental run: Russet potato, "julienne" strips five thirty-seconds inch square, steam-blanched 6 minutes, wood-slat trays, original load 1.5 pounds per square foot of tray surface, air flow across the trays, air velocity 500 feet per minute, air temperature 150° F., wet-bulb temperature 90°. If these conditions are maintained constant and the progress of drying is determined from time to time by weighing the tray, a drying curve such as that reproduced in figure 26 may be drawn.

This curve is typical of hundreds that have been observed. Two characteristics are especially important: (1) The very rapid initial fall in moisture content, and (2) the very slow final approach toward equilibrium moisture content (in this case, from figure 26, equilibrium $T=0.025$, about 2.5 percent). Note that an entire hour is consumed in drying from 7 percent to 6 percent moisture, whereas three-fourths of the total original moisture is evaporated in only an hour and a quarter.

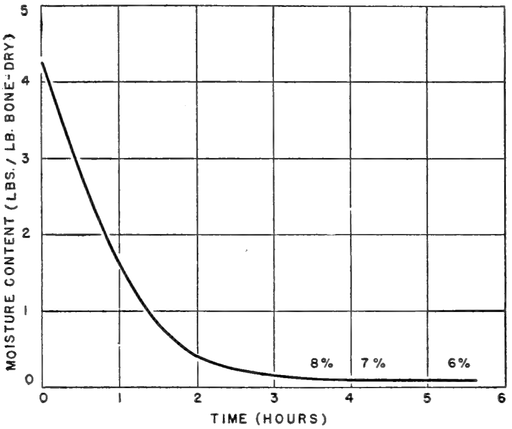

FIGURE 26.—A typical drying curve.

Effect of Wet-Bulb Depression

Other things being equal, drying will proceed faster if the wet-bulb depression of the air is high (relatively dry air) than if it is low (relatively moist air). Figure 27 compares drying curves for potato strips in three experiments; in all of them the wet-bulb temperature of the air was 90° F., but dry-bulb temperature was 105° in one case, 130° in another, and 150° in the third, so that wet-bulb depressions were 15°, 40°, and 60°, respectively. The very great effect of this factor is apparent.[5]

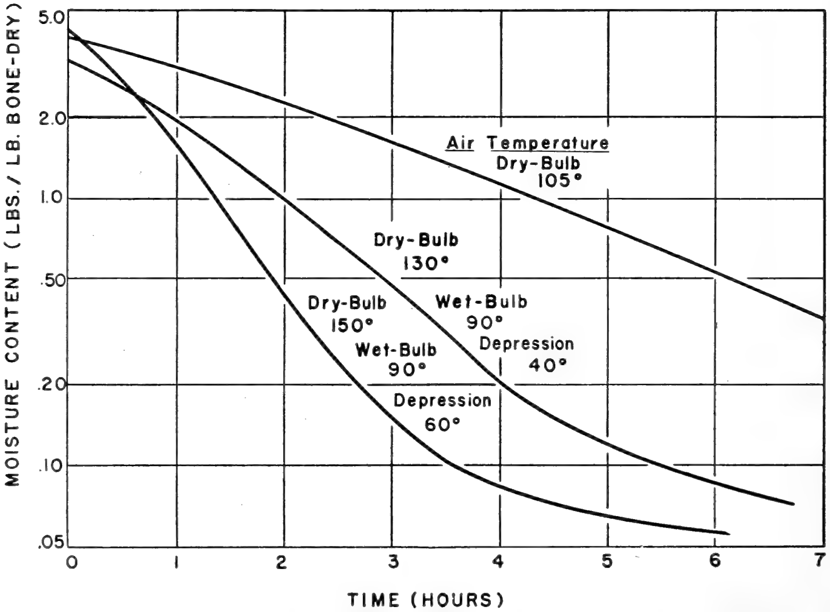

FIGURE 27.—Drying curves for potato strips at varying dry-bulb temperatures.

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[5] In this figure and the other drying curves which follow it, a logarithmic scale for moisture content is used, in order to show differences at low moistures more effectively.

Effect of Temperature Level

At a given wet-bulb depression, drying will proceed faster if the temperature level is high than if it is low. Figure 28 compares the results of two runs, in both of which the wet-bulb depression was 40° F.; in one, however, the temperatures were 90° and 130°, while in the other they were much higher, 120° and 160°. In the latter the rate of drying was substantially faster. Note, however, that the effect was less marked than that of wet-bulb depression as shown in figure 28. That is, if dry-bulb temperature were the same in two runs, the one at the higher wet-bulb temperature would be the slower because of the predominant effect of wet-bulb depression.

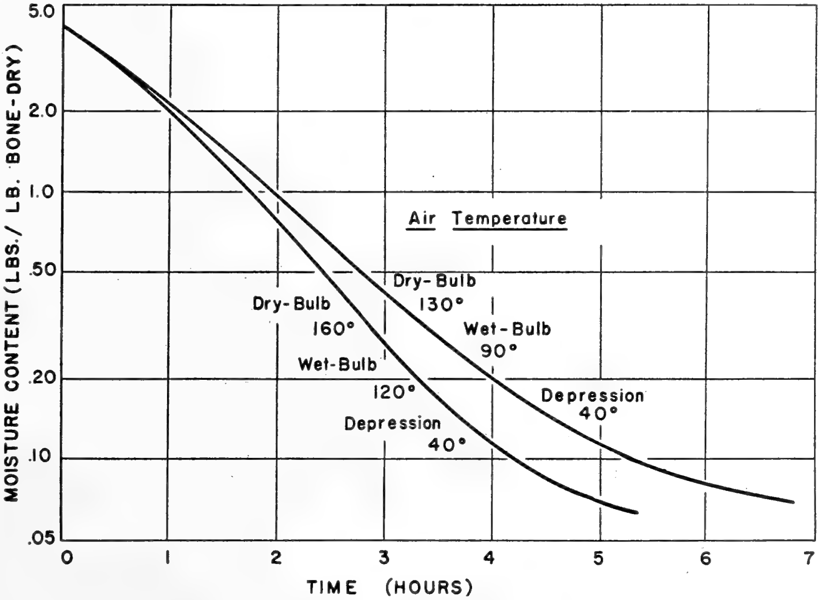

FIGURE 28.—Drying curves obtained with differing temperatures but with the same wet-bulb depression.

Effect of Air Velocity

The higher the velocity of air over a moist surface, the more rapid the evaporation from that surface. Figure 29 compares drying curves from experiments with potatoes. Air velocity across the tray was 500 feet per minute in one case, 675 in another, and 855 in the third. Drying was somewhat more rapid with higher air velocity. The effect of air velocity is much more substantial in drying cabbage and leafy vegetables in general than it is in drying potatoes.

A change in the air velocity in a dehydrator has two quite independent effects. One is the effect on drying rate, which has just been described. The other will be considered more fully in a following section, and, in brief, is a consequence of the fact that the weight of air moved through the dehydrator rises in proportion to the velocity of that air. The greater the weight of air circulated, the less it will fall in temperature for a given amount of evaporation, and hence,

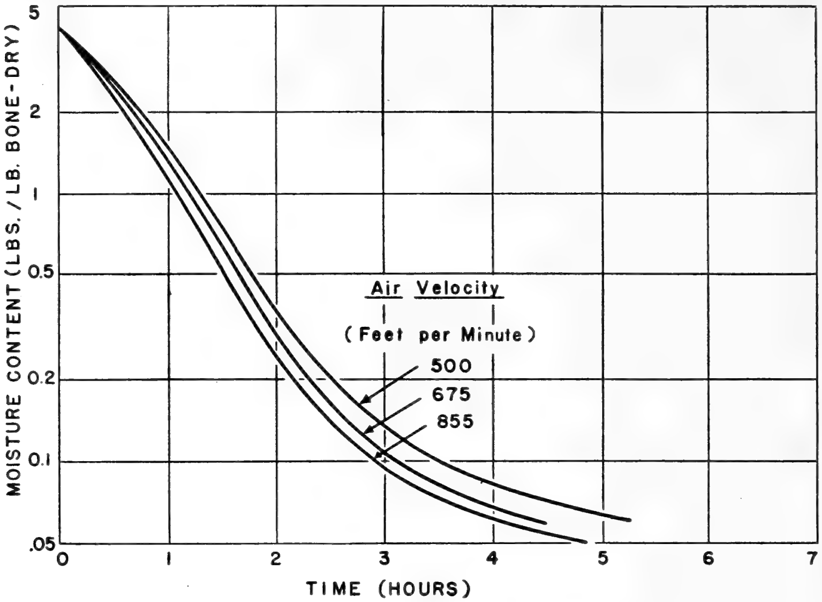

FIGURE 29.—Drying curves obtained with varying velocities of air.

the higher the wet-bulb depression that will be maintained in the dehydrator.

Manner of Exposure to Air Stream

In commercial dehydrators the pieces of vegetable are not suspended separately in the air stream, but must be piled on one another, or on a support. Contact with the air stream is thus hindered. The lower pieces in a deep layer will dry very slowly if air flows only across the top.

In some types of dehydrator the air is caused to flow through the layer of pieces, which are held on a perforated support. This is known as through circulation. It exposes all pieces, even in a deep layer, to contact with the entire flow of air. If the air flow is across, or substantially parallel to, the surface of a layer of pieces, the arrangement is known as cross circulation. A relatively thin layer must be used in a cross circulation drier and an effort is usually made to expose the bottom of the layer at least partly to the air stream by using some form of perforated support.

The experimental results presented above (figs. 24 to 29) all come from cross-circulation runs. The air velocity referred to is the velocity in the main air stream, above the layer of material.

Direct comparison with a through-circulation experiment is difficult, because there will usually be several differences in conditions, not just the difference in arrangement. It is practically impossible, for example, to run air through a deep layer as rapidly as it is usually blown across a tray; indeed, the very meaning of the term "air velocity" must be defined carefully or the comparison means nothing. The commonest way of expressing air flow through a layer is to give the cubic feet of air flowing per minute through a square-foot cross section of the layer. A more precise measure, in view of the fall in temperature of the air as it passes through the layer, is the weight of air per minute per square foot. The latter is known as mass velocity.

In general the drying rate is affected very much more by thickness of layer in a cross-circulation drier than in a through-circulation drier. If a very thin layer were exposed on an open-mesh support, drying rates would probably be nearly the same for air flow across the layer as through it. On the other hand, complete drying of a layer of vegetable pieces several inches deep would be practically impossible by pure cross circulation but would take place rapidly by through circulation.

In some dehydrators of the tray type an effort is made to induce at least a part of through circulation either by baffling the air stream or by slanting the trays at an angle to it. Substantial savings in drying time, ranging as high as 20 percent, have been reported as a result of slanting trays.

Effect of Thickness of Layer

The slowing down of drying as the thickness of layer of wet material spread on trays in a cross-circulation drier is increased is illustrated by figure 30. The thickness is indicated by the values given for weight of moist material spread on a square foot of tray surface.

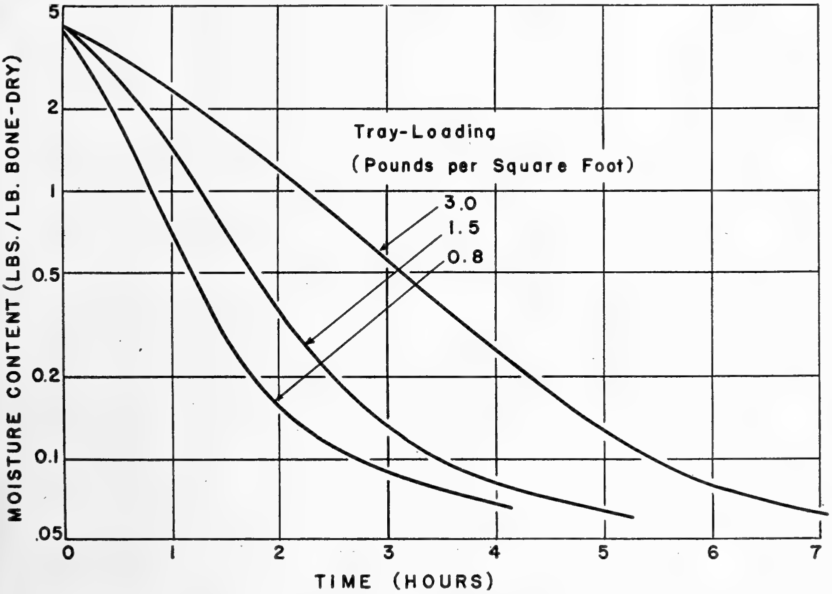

FIGURE 30.—Effect of depth of layer of material on drying time in a tray-type dehydrator.

With fairly light loadings the drying time increases more slowly than the rate of increase in loading; that is, doubling the loading does not double the drying time. Since the output of a given dehydrator depends on the quotient of these two factors, the output may be increased by loading trays more heavily—up to the point where a further increase in loading is just compensated by a proportional increase in drying time. If the loading is increased beyond this point the output of the dehydrator will actually fall off. Figure 31 presents imaginary curves that show relative capacity of a particular dehydrator at various loadings per square foot of tray. The curve for cabbage shreds indicates that this dehydrator will reach its maximum capacity when the trays are loaded about 1.1 pounds per square foot; the curve for potato strips appears to reach its maximum capacity at a load of about 2 pounds per square foot. The drying times marked on the curves indicate, however, a rapid increase in drying time at the heavier loadings.

Drying time can be considerably shortened by the use of a load somewhat lighter than the one that will give maximum output, and the sacrifice of capacity will only be minor. In view of the well-established fact that rapidly dried vegetables are superior in quality to slowly dried ones, the wisdom of moderate loadings is apparent.

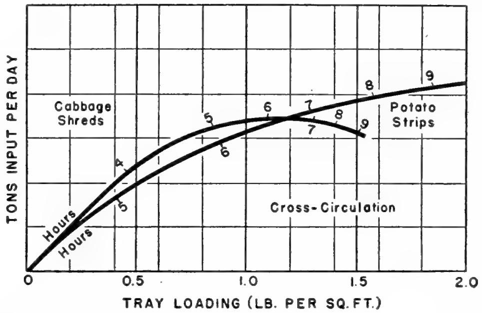

FIGURE 31.—Relationship of loading of trays to daily capacity of a dehydrator. (A numerical scale of tons input per day is not shown, because that will depend on the kind of vegetable being dried, tray loading, total tray surface and the temperature, humidity, and velocity of the circulating air.)

Character of the Support

In a cross-circulation drier, drying time is substantially shortened by supporting the moist material on a wire-mesh surface such as hardware cloth, which is high in heat conductivity and open to air circulation. The support, whatever its construction, tends to reach the dry-bulb temperature of air circulating past it; if its conductivity is high, the product resting on it will warm up above wet-bulb temperature even while very moist, and will therefore dry faster. If the conductivity is low, as in wood trays, the effect on product temperature will be much less.

While the metal tray offers this advantage in drying rate, certain other considerations favor wood-slat trays. Since corrosion-resistant alloys and tinned screens are difficult to obtain under wartime conditions, galvanized screen is the most common type of metal-tray bottom. Corrosion of the screen and darkening of the product in contact with the mesh may be experienced. Synthetic resin varnishes are being used to some extent as protective coatings. Fruits generally cannot be dried successfully on galvanized-screen trays.

Manner of Preparation

Fruits that are dried whole, for example prunes and cranberries, are usually pretreated in a manner to rupture the tough, waxy skin so that drying will be accelerated. Vegetables, on the other hand, are always dried in the form of cut or formed pieces. The pretreatment they receive, particularly blanching, has a complex effect on the rate of drying.

Blanching has a marked effect on the physical structure of potato pieces. Starch granules swell, a certain amount of soluble salts is leached out, a layer of gelatinous starch may be formed on the surface. There is little information on the effect of these changes on the speed of drying, mainly because present practice invariably includes blanching. The same situation exists with regard to other vegetables. There is experimental evidence, however, that there is no material difference between the rate of drying of potato strips blanched 4 minutes and those blanched 10 minutes in atmospheric steam. It is well known that vegetables made soft by blanching must be handled with care to prevent the formation of "mush" on the trays, since mush dries very slowly. The tendency of blanched leafy vegetables to "mat down" also limits the depth to which they can be piled, especially in a through-circulation dehydrator.

Shape and Size of Pieces

Internal resistance to diffusion of moisture is the controlling influence during most of the drying of vegetables and fruits in commercial sizes. The shape and size of the pieces is therefore a very important factor in determining rate of drying. Figure 32 compares drying curves for potato strips of three different thicknesses. Cubes generally dry faster than strips of the same cross section, and slices of the same thickness dry slower than either.

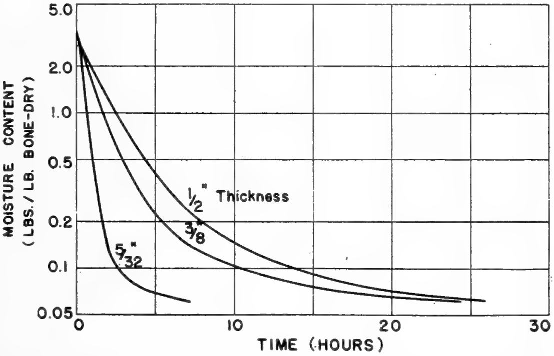

FIGURE 32.—Effect of thickness of potato strips on drying time.

Nature of the Fruit or Vegetable

Figure 33 presents typical drying curves for two common vegetables and one stone fruit. While these curves are not strictly comparable with regard to density of loading, size of piece, and other factors, they illustrate the general range of differences between products.

The drying rates show the widest divergence at low moisture content, but there are substantial differences at all levels. In general, materials that are initially very high in moisture have the higher drying rates. The length of time required to reach, say, 10 percent moisture bears no apparent relation to initial moisture content; it is more likely that a relation could be traced with the amount and kind of sugars and other soluble substances present in solution.

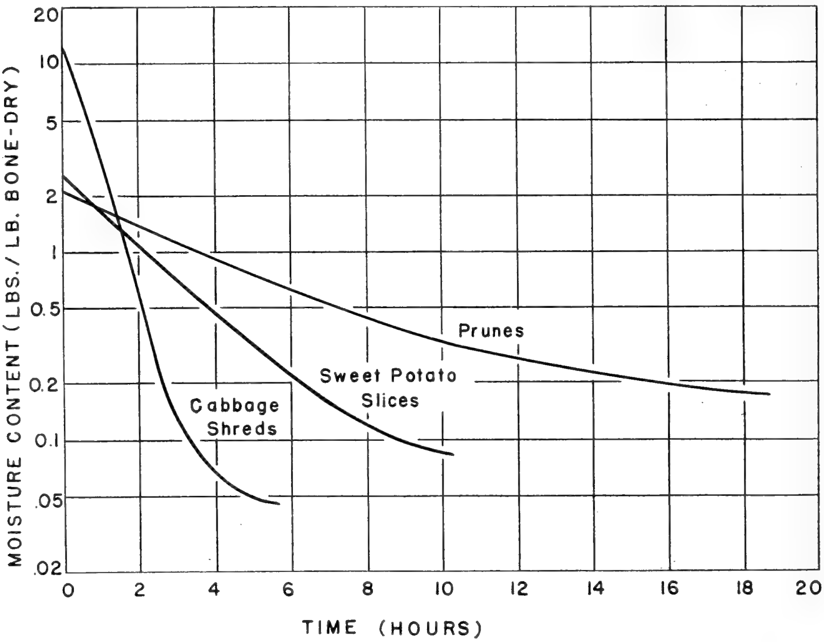

FIGURE 33.—Typical drying rates for three types of product.

Estimation of Drying Time

It should be apparent that the question, "How long does it take to dry carrots?" can be answered only when a considerable number of factors are specified. A reasonably good estimate of drying time is a necessary element in dehydrator design, and it is now possible to supply such estimates for many important cases as a result of correlation of hundreds of experimental drying runs.[6]

The operator will not usually have any need for this information, except in a qualitative way. The foregoing discussions indicate that in general the following factors favor rapid drying: Thin pieces, open metallic support, light open piling, circulation of air through entire layer, high velocity of air past the moist material, high temperature level, high wet-bulb depression.

Drying Conditions Within a Dehydrator

Drying conditions within a dehydrator operating with commercial loads are never so simple as those of the experiments that have just been described. In particular, the air temperature and humidity al-

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[6] Information on the drying characteristics of a number of vegetables may be obtained from the Western Regional Research Laboratory, Albany, Calif.

ways change materially during the course of drying any given piece or tray load of vegetables. The air velocity will change correspondingly, or it may be changed purposely as the drying progresses. Both the capacity of the dehydrator and the quality of the product are affected by the manner in which these changes occur.

Cooling of Air Due to Evaporation

The heat required to evaporate water is supplied, in all common types of hot-air dehydrators, by the circulating air itself. The heat absorbed by evaporation is taken away from the air; consequently the air cools. This cooling effect is very substantial; as a rough average for commercial conditions, when 1,000 pounds of air takes up 1 pound of water vapor by evaporation the air cools 5° F. (*44*).

For example, air at 160° F. dry-bulb and 95° F. wet-bulb temperature has an absolute humidity of 0.021, so that 21 pounds of water vapor accompany each 1,000 pounds of dry air. The humid heat of the mixture is 0.249. If one more pound of water, assumed to be at the wet-bulb temperature (95°), is evaporated into this air, the latent heat absorbed is 1,040 B. t. u. In addition, the water vapor will be heated up to the new dry-bulb temperature of the air, and the specific heat of water vapor is 0.45, so approximately 27 more B. t. u. will be required, or a total of 1,067 B. t. u. The mixture will therefore cool down $\frac{1{,}067}{1{,}021 \times 0.249} = 4.2°$. If there is only 1,000 pounds of the original mixture, instead of 1,021 pounds, the cooling will be 4.3°.[7]

Evaporation of 1 pound of water into 1,000 pounds of air corresponds to a rise of 0.001 in absolute humidity. If the point corresponding to the new mixture, having a temperature of 155.8° F. and an absolute humidity of 0.022, is spotted on the humidity chart, it will be found that the wet-bulb temperature is still just 95°. This is an important general rule, namely: **When water evaporates into air without loss of heat to, or gain of heat from, the surroundings, the wet-bulb temperature of the air remains unchanged.**

In commercial dehydrators the ideal conditions of this example are never fully realized; the incoming product has to be heated up to wet-bulb temperature, and trucks and trays have to be warmed up; there will be losses of heat to the surroundings through the dehydrator walls, and heat may be gained from an adjacent heating chamber. Nevertheless these losses and gains are usually small in comparison with the main effect. Commercial dehydrators usually run with a wet-bulb temperature that falls only a degree or two between the hot end and the cool end. Dehydrators designed to reheat the air at intervals during its passage through the equipment will, of course, exhibit a rising wet-bulb temperature, but in any section where the only process is one of evaporation the wet-bulb temperature will remain substantially constant.

Since the fall in dry-bulb temperature of the air is proportional to the weight of water evaporated into a given weight of air, there is a direct parallelism between the extent of drying of the moist material at any point in its passage through the dehydrator and the fall in air temperature to the same point. The exact relationship will depend

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[7] The 5° F. cooling given in the preceding paragraph makes a reasonable allowance for losses of heat in commercial dehydrators.

on the arrangement of the dehydrator, but a simple example will illustrate the principle involved:

Suppose that in a simple counterflow tunnel dehydrator air is circulating at the rate of 2,000 pounds per minute. Its dry-bulb temperature at the point of entrance is 165° F. Suppose that 18,000 pounds of prepared carrots enter the tunnel during 24 hours; original moisture content is 8.5 pounds of water per pound of bone-dry matter ($T_o=8.5$), and the product is dried in the tunnel to a final moisture of 4.76 percent, ($T_f=0.05$). On the average, 12.5 pounds of carrots per minute enter the tunnel, and the weight of water evaporated (see p. 54) is $12.5\times\frac{8.5-0.05}{8.5+1}=11.1$ pounds per minute. Then the rise in absolute humidity of the circulating air is $\frac{11.1}{2{,}000}=0.0055$. If the fall in air temperature is 5° for each 0.001 increase in absolute humidity, the total temperature fall through the tunnel will be 27.5°, and the temperature of the exhaust air will be 137.5°.

Furthermore, the temperature fall between any two points in the tunnel will be proportional to the change in moisture content of the product between the same two points. What will be the temperature at the point in the tunnel where the moisture content has fallen to $T=1.0$? In a counterflow dehydrator the hot air enters the dry end of the tunnel. Evaporation between the dry end and the point where $T=1.0$ is $12.5\times\frac{1.0-0.05}{8.5+1}=1.25$ pounds per minute; the rise in absolute humidity is 0.000625, and the fall in temperature is about 3° F. The temperature will be about 162°. While the application of this principle may be difficult because of the design of a particular dehydrator, it is valid for any arrangement and will usually give a reasonably satisfactory answer regarding temperature changes in the equipment.

Maximum Evaporation Capacity of a Dehydrator

If the two principles regarding temperature change are considered together, a useful criterion for the maximum evaporative capacity of any given dehydrator can be formulated. Note first that when the air temperature falls until it is equal to the wet-bulb temperature, the air is saturated and no further evaporation can occur. In fact, the air could never cool quite that far through evaporative cooling alone, because additional evaporation becomes slower and slower as the air nears saturation. Then, since the wet-bulb temperature of the air remains substantially constant, the maximum amount of evaporation that can take place can be predicted at once if the original dry-bulb and wet-bulb temperatures and the weight of air circulating are known. The maximum possible fall in temperature is from the original dry-bulb temperature to the original wet-bulb temperature (if the usual slight fall in wet-bulb temperature is neglected).

Suppose that in the preceding example the wet-bulb temperature of the air is 100° F. Then the maximum evaporative capacity of that particular counterflow tunnel would correspond to a fall in air temperature from 165° to 100°, or 65°. The corresponding increase in absolute humidity of the air will be about 0.013, and if the air flow is 2,000 pounds per minute the maximum evaporation will be about 26 pounds of water per minute.

Commercial dehydrators always represent a compromise between high evaporating efficiency and high drying rate. If the air is discharged nearly saturated, as it must be to attain full value from the air circulation, the drying rate throughout a large part of the equipment will be very low. Choice of the weights to be given to these opposing factors will be based partly on relative costs and partly on considerations of product quality. The standard fruit dehydrators which are common in the West, generally operate at high air efficiency and are correspondingly slow driers; air is usually exhausted from them at 65 percent relative humidity, or even higher. Modern vegetable dehydrators, on the other hand, may exhaust air at only 30 to 40 percent relative humidity, since both the economic and the quality factors favor such a course.

A half or more of the theoretical maximum evaporative capacity will purposely be left unutilized, so as to promote reasonably rapid drying throughout the entire time the product is in the dehydrator. This purpose is attained by maintaining a high ratio of air flow to rate of input of wet material. Note that in the examples just given, the rate of evaporation was to be only 11.1 pounds of water per minute, while the theoretical maximum was 26 pounds per minute; only 43 percent of the evaporating capacity would be utilized. This would favor rapid drying.

Experimental Determination of Drying Time

The foregoing principles make it possible to obtain a reasonably precise estimate of the drying time for any particular product in a given dehydrator through not more than three experiments in a small cabinet drier (see subsequent section on cabinet dehydrators). The drier should be designed so that the ratio of air flow to evaporation will be very large, since then the change of air temperature in passing across the moist product will be negligible. Air temperature and wet-bulb temperature must be controllable by the operator at all times. The moist material will be carried in the same manner as it will be in the commercial dehydrator (for example, on the same type of tray), and the air velocity will be made the same. The tray will be so arranged that it can be quickly and accurately weighed at intervals, in order to keep a running check of the moisture content of the material on the tray.

Suppose it is desired to estimate the time required to dry carrots in the counterflow dehydrator mentioned previously. Since the wet-bulb temperature in the tunnel was to be 100° F., that wet-bulb temperature will be maintained in the experimental cabinet throughout the run. The dry-bulb air temperature at the exhaust or wet end of the tunnel was to be 137.5°, and at the dry end 165°. The experimental run, then, will start at 137.5° and end at 165°. The temperature will be raised during the progress of the run in proportion to the fall in moisture content of the product, as illustrated in figure 34. In practice the adjustment of temperature will be made in small steps, as shown in the diagram. The time required for drying will then approximate the time that would be necessary in the commercial dehydrator.

If the dehydrator is of a more complex type, three such experimental runs may be necessary. For example, in a center-exhaust tunnel (described in a subsequent section), the operation changes from parallel flow to counterflow at a fixed proportion of the total drying time, this proportion being determined by the relative lengths of the two ends of the tunnel. In a drying experiment the total time is unknown until the experiment is complete, and hence the point at which the simulated change-over should be made is unknown. Under these circumstances it is necessary to run three experiments, with a different moisture content selected as the point of change-over in each. The result that would have followed at the proper ratio between times may then be interpolated.

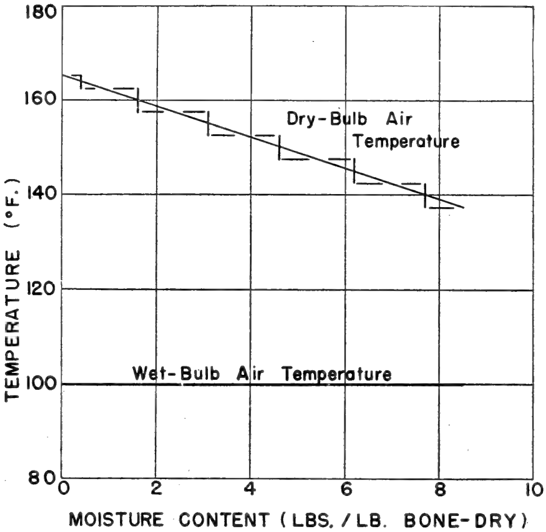

Figure 34.—Conditions for the determination of drying time.

Experimental determinations of this kind should, of course, be so discounted as to allow for the usual imperfections of a commercial dehydrator, such as useless short-circuiting of air and down-time while trucks are being moved.

Effects of Recirculation of Air

The air leaving the cool end of a commercial vegetable dehydrator of the usual tunnel type is likely to have a temperature of at least 100° F. and sometimes even 120° or higher. A very substantial saving in heat can be made by letting only a part of this air escape and mixing the remainder with the fresh air flowing to the heater. This is "recirculation," one of only three factors which the dehydrator operator can easily control; the other two are hot-end temperature and the rate of charging wet material into the tunnel.

It may seem puzzling that any of this relatively cool, moist air can serve any useful purpose if returned. The fact is that addition of humidity to the circulating air is essential in the dehydration of heavy fruits, and may be advantageous, although to a smaller degree, in the dehydration of a sweet vegetable—for example, sweetpotatoes. This effect—the avoidance of case-hardening—has already been briefly discussed. Most vegetables can be most rapidly and completely dehydrated with air of low humidity. When that is the case, the main advantage of recirculation lies in the saving of heat, and this saving will be at least partly offset by slower drying and lower drying capacity.

Study of typical operating conditions discloses that it is possible to recirculate a substantial proportion, say 50 to 75 percent, of the air in commercial tunnel dehydrators, and realize a considerable saving in the cost of heat without serious loss of tunnel capacity. Figure 35 illustrates these relations on a skeleton humidity chart. Point *S* represents the temperature and humidity of the fresh air. If the temperature, designated *t′*, is the desired hot-end temperature, then point *U* represents the condition of the air entering the hot end; its absolute humidity is the same as that of the fresh air. In passing through the tunnel, its temperature will fall and its humidity will rise, ending at the cool end of the tunnel at a point on the chart such as *V*.

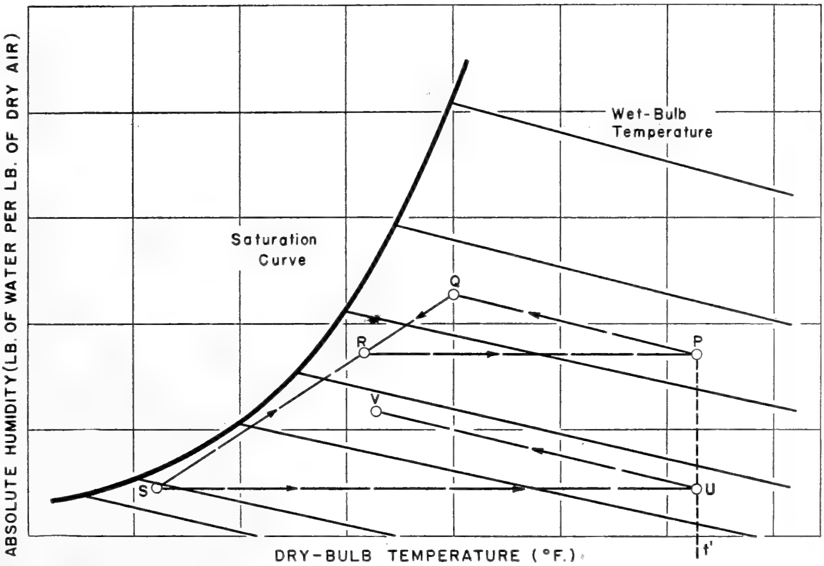

FIGURE 35.—Effect of recirculation of air on amount of heat required.

If there is no recirculation, all of this air will be discarded and fresh air will be heated from *S* to *U*. But if, say, only one-third of the exhaust air is discarded, and only that difference is made up with fresh air, then humidity rises in the tunnel, and after a short time new steady conditions are set up, represented by points *P*, *Q*, and *R* on the chart. The air at the hot end of the tunnel will still be heated to the same temperature as before (*t′*) but its humidity will be higher (*P*). In passing through the tunnel, its condition will change to that indicated by *Q*. The mixture of one-third fresh air and two-thirds exhaust air will be represented by *R*. The amount of heat required is represented roughly by the length of the line *RP*, which is much shorter than the one representing no recirculation, *SU*. The increase in wet-bulb temperature and the corresponding decrease in evaporative capacity, however, are only moderate.

The proportion of recirculation may be readily calculated by the use of the following formula:[8]

$$r=\frac{a'-a_0}{a''-a_0}$$

where r = proportion of the circulating air that is recirculated,
then $1-r$ = proportion of fresh air in the mixture,
a_0 = absolute humidity of the incoming, or fresh air,
a' = absolute humidity of the mixture as it enters the dehydrator,
and a'' = absolute humidity of the air as it leaves the dehydrator, to be partly recirculated.

Example: Suppose that a counterflow tunnel is operating at a wet-bulb temperature of 100° F., a hot-end temperature of 165°, and a cool-end temperature of 137.5° F. The fresh air drawn in has a temperature of 60° and a wet-bulb temperature of 55°. What are the proportions of recirculation and fresh air intake?

From the humidity chart, figure 23, $a_0=0.0080$, $a'=0.0271$, $a''=0.0337$. Then $r=0.743$, or 74.3 percent, and $1-r=0.257$, or 25.7 percent. If air is circulating in the dehydrator at a flow of 2,000 pounds per minute, the fresh-air intake will be 514 pounds per minute.

In a complex dehydrator the formula may be used by applying it separately to sections where conditions are known at both ends. For example, the "fresh air" supplied to the primary end of a center-exhaust dehydrator may consist partly or wholly of air exhausted from the secondary section of the dehydrator.

Control of recirculation enables the operator to maintain substantially uniform drying conditions regardless of variations in atmospheric conditions. If the humidity of the fresh air rises, the proportion of recirculation can be reduced to compensate for the change. Even in subtropical climates, compensation is possible without carrying a very high wet-bulb temperature in the dehydrator. For example, on a very humid summer day the absolute humidity may rise to 0.025; if the dehydrator hot-end temperature is 150°, some recirculation will still be required to hold a wet-bulb temperature of 96° or above. This compensation by varying the recirculation is attended by variation of the heat requirement of the dehydrator, as will be shown in the following section.

Heat Usage in a Dehydrator

The necessity of supplying from some source at least 1,000 B. t. u. of heat for each pound of water evaporated has already been pointed out. It is not necessary theoretically that this heat be supplied from an artificial source; water evaporates from the washing hung on a clothesline without any consumption of fuel. Even in that case, however, the heat absorbed in evaporation is reflected in a cooling of the air blowing past the wet clothes.

From the practical standpoint that type of natural evaporation is too slow and uncertain to be used for dehydrating vegetables, although it is extensively used for drying prunes and apricots. Dehydration of vegetables is speeded up and made controllable through the application of artificial heat. In commercial dehydrators the heat actually

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[8] The effects of leakage from the dehydrator and water vapor added by direct combustion of fuel are neglected in this formula.

supplied to the circulating air varies between about 1,500 and 6,000 B. t. u. per pound of water evaporated. The requirement varies both with the type of dehydrator and with the conditions of operation; it is partially within the control of the operator.

The heat consumption of most types of dehydrators may be estimated approximately from the following formula:[9]

$$B=1{,}250\left[r+(1-r)\frac{t'-t_o}{t'-t''}\right]$$

where B=heat that must be supplied, B. t. u. per pound of water evaporated,

t_o=temperature of the incoming, or fresh air, in ° F.,

t'=temperature of the mixture as it enters the drying section of the dehydrator, and

t''=temperature of the air as it leaves the drying section of the dehydrator, to be partially recirculated.

Example: In the simple counterflow tunnel used in previous examples, $r=0.743$, $t_o=60°$, $t'=165°$, $t''=137.5°$. If these values are substituted in the formula, $B=2{,}150$ B. t. u. per pound of water evaporated. If the evaporation is 11.1 pounds of water per minute, as in preceding examples, the necessary heat input is 1,430,000 B. t. u. per hour.

In a complex dehydrator this formula can be used to estimate the heat requirement of separate sections, provided the necessary information is available for each section.

Even though this estimate makes some allowance for ordinary heat losses, the designed heating capacity of a dehydrator will normally be increased generously over the estimate in order to allow for air leakage and unforeseen exigencies of operation. Excess heating capacity will allow the operator a desirable degree of flexibility in choosing conditions under which the dehydrator shall work, particularly the wet-bulb temperature level.

Consideration of the formula for heat requirement brings out the following relationships:

1. **The higher the proportion of recirculation, other things being equal, the lower will be the heat consumption.**

Example: If the dehydrator in the previous example were operated without recirculation, but at the same rate of evaporation and same hot-end temperature as before, the heat usage would be 4,750 B. t. u. per pound of evaporation, or 3,180,000 B. t. u. per hour. The wet-bulb temperature in the tunnel would be lowered from 100° F. to 86°.

2. **For given conditions inside the dehydrator, the heat consumption will be higher if the outside air is colder or if its humidity is higher.**

Example: Consider conditions in the counterflow dehydrator maintained at 100° F. wet-bulb temperature, hot-end temperature 165°, cool-end temperature 137.5°.

a. The heat consumption when the outside air has a temperature of 60° F., wet-bulb temperature of 55°, has already been calculated as 2,150 B. t. u. per pound of evaporation, 1,430,000 B. t. u. per hour. What will it be if the outside temperature is 5°, wet-bulb 4°? From

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[9] The coefficient 1,250 is the product of 5° F. (change in temperature per 0.001 increase in absolute humidity), divided by 0.001 (to convert to pounds of water evaporated per pound of air), multiplied by 0.25 (average humid heat of air in the dehydrator). It makes a reasonable allowance for ordinary heat losses.

the humidity chart, $a_o=0.0005$. Then $r=0.800$, $B=2{,}460$ B. t. u. per pound, or 1,640,000 B. t. u. per hour.

b. What will be the heat consumption if the outside air has a temperature of 90° F., wet-bulb 65° (arid conditions, 24 percent relative humidity)? $a_o=0.0075$, $r=0.748$, $B=1{,}800$ B. t. u. per pound or 1,200,000 B. t. u. per hour.

c. What will be the heat consumption if the outside air has a temperature of 90° F., wet-bulb 85° (tropical conditions, 82 percent relative humidity)? $a_o=0.0247$, $r=0.267$, $B=2{,}830$ B. t. u. per pound or 1,890,000 B. t. u. per hour.

3. **The greater the load of evaporation that is put on a given dehydrator, the more efficient will be the utilization of heat, but the greater will be the amount of heat required per hour.**

Example: Consider that in the simple counterflow tunnel the input of moist carrots is increased from 18,000 pounds to 24,000 pounds during 24 hours. The weight of water to be evaporated will increase from 11.1 pounds per minute to 14.8 pounds per minute, and the temperature will fall at the cool end to 128° instead of 137.5°. If the wet-bulb temperature is 100°, $a'=0.0271$ as before, but $a''=0.0360$. If the humidity of the fresh air, $a_o=0.0080$, and $t_o=60°$, $r=0.682$, $B=1{,}980$ B. t. u. per pound (a decrease of 8 percent), but the heat usage per hour is 1,760,000 B. t. u. (an increase of 23 percent.)

Balance Between Efficiency and Effectiveness

It is evident that the operator has it within his power to change to some extent the cost of heat used in the process, through his control of the wet-bulb temperature. He may be confronted, however, with the necessity of choosing between low heat cost and high output of dry product. The matter of striking a proper balance between the two is largely a question of relative costs, but it is also affected by the influence of dehydrator conditions on the quality of the product. That subject is discussed in the following section.

EFFECT OF DRYING CONDITIONS ON QUALITY OF PRODUCT

The dehydration of fruits and vegetables is primarily a technique of preserving a perishable food product. The product must retain the qualities of an acceptable food or the entire purpose of the process is defeated. Consideration of the drying step solely from the standpoint of efficient evaporation of moisture would therefore be fatally one-sided. Certain hazards that are encountered during the drying process are discussed here briefly; reconstitution and quality of finished products are treated in subsequent sections.

Heat Damage—Scorching

The temperature to which a piece of fruit or vegetable can be heated is limited by the occurrence of scorching. The reconstituted and cooked product must have the best possible appearance, flavor, and texture. It must be free from the characteristic flavor and browning produced by scorching.

Scorching occurs in some materials at much lower temperatures than in others. Sweetpotatoes, sweet corn, and spinach and other green leafy vegetables will stand much higher temperatures without scorching than will onions or cabbage. Carrots and rutabagas are intermediate in sensitiveness. Potatoes are almost as sensitive as cabbage (*31*). Variety, maturity, and manner and length of storage before use may have decided effects upon safe dehydration temperatures. The directions for drying specific commodities given in later sections are based upon average qualities of the vegetable varieties usually dehydrated, and will require varying amounts of modification for various types of raw material.

Scorching is an effect not only of temperature but also of time. The characteristic marks of damage will appear at temperatures as low as 120° F. if the time of exposure is long enough. Very roughly, the time required to produce noticeable scorching will be cut in half for each 15° of rise in temperature.

The moisture content of the material also appears to have an influence on sensitiveness to temperature, according to Mangels and Gore (*31*). The conclusion reached as a result of relatively few experiments is that signs of scorching occur in a shorter time if the moisture content is 10 to 15 percent than if it is lower. A few observations on the drying of cabbage at high wet-bulb temperatures have indicated heat damage within a few hours at 110° F. wet-bulb, even though the material was still very moist.[10] Scorching apparently occurs as readily in a vacuum as in air.

Damage to Nutritive Quality

The drying processes currently used for fruits and vegetables have little adverse effect on the nutritive value of the products. Carbohydrates, fats, proteins, and most of the vitamins come through the drying with substantially no loss. The one major exception is ascorbic acid. This vitamin is lost in all stages of preparation and drying, and continues to disappear during storage of the dried product. Loss during the drying step ranges from less than 10 percent to more than 75 percent; it occurs both while the material is very moist and when it is nearly dry, at approximately equal rates. The effect of product temperature on the rate of loss has not been determined. Since the disappearance of ascorbic acid is probably caused by oxidation, drying in a vacuum or an inert gas instead of air would presumably decrease the rate of loss.

Damage to Color and Flavor

Scorching is recognizable through the development of a yellow or brown color, the appearance of a burnt flavor, or both. Careful measurements of color show that some yellowing occurs, and frequently some bleaching of the natural color, even if the drying is completed without such gross damage as would be classified as scorching. These changes are apparently effects of both time and temperature, but the exact connection has not been established.

Effects of drying on the flavor of the product, aside from scorching, are generally in the direction of loss of characteristic aroma and taste, probably through the evaporation and loss of volatile flavoring substances. The presence of these substances is sometimes conspicuously

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[10] The important temperature is that of the piece itself. While the piece is moist this may be close to the wet-bulb temperature of the air; later it will be close to the dry-bulb temperature. Thin edges and corners will dry rapidly, while the rest of the piece is still much cooler, and may be the only portions that show heat damage.

evident in the exhaust air. The general rule for minimizing this loss of quality is to keep the temperature of the material relatively low, but to keep the rate of drying as high as possible. Since the first of these two measures slows down the rate of drying, any choice of conditions will be a compromise based on experience.

Drying conditions that expose the wet product for several hours to warm air high in humidity are very unfavorable to product quality. Under such conditions the growth of bacteria and molds may be exceedingly rapid, and the product may become sour or moldy before the drying has progressed far enough to check further growth of the micro-organisms. Drying should start promptly and proceed rapidly to prevent this kind of damage. Trouble from this source may be experienced in the drying of vegetables in a counterflow tunnel dehydrator if the tunnel is so long or the flow of air so slow that the air temperature drops to only 5° or 10° F. above wet-bulb temperature at the cool end.

CONVEYOR-BELT DEHYDRATORS [11]

Figure 36 illustrates diagrammatically a commercial form of conveyor dehydrator. The wet material is loaded evenly, and relatively deeply, on a traveling conveyor. Hot air is blown through the layer of material and through the conveyor belt itself. The direction of flow of the air may be reversed once or oftener in successive sections of the drier, and the thickness of the layer of material may be maintained, or increased, in spite of shrinkage, by transfer of the material to a conveyor that moves more slowly.

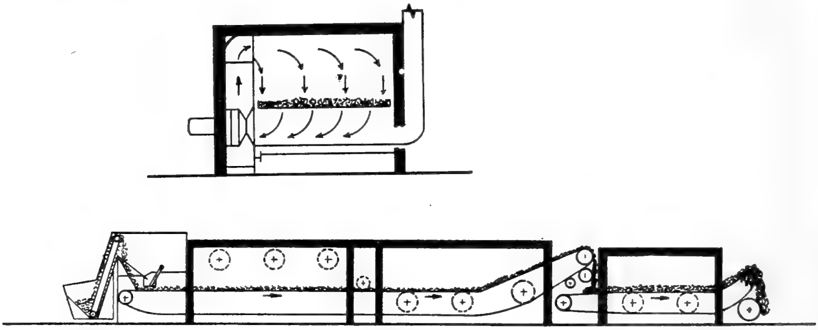

FIGURE 36.—Structural features of the conveyor dehydrator.

The conveyor drier is one of the important types of equipment in the current vegetable-dehydration program. It is fundamentally automatic in operation, and may therefore be preferred in a highly mechanized plant. Unless a relatively thick layer of material is carried on such a conveyor, the size of drier required becomes excessive. For example, if 30 tons of moist vegetable are to be dried per 24 hours, and the drying time cannot safely be reduced below 3 hours, then 6,250

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[11] While patent files and other publications describe hundreds of different designs for food dehydrators, present commercial interest centers in less than a dozen general types. In the following pages those types that are used most extensively for vegetable and fruit dehydration are discussed in greater detail than are the others. Each type of dehydrator has a preferred field of use. Most commercial production of dried vegetables and fruits is obtained through the use of continuous hot-air types of driers. The noncontinuous, or batch-type driers, are also used considerably and are valuable for experimental work.

square feet of conveyor surface would be required if the loading were only 1.2 pounds per square foot, but would be only 625 square feet if the loading could be increased to 12 pounds.

Drying a thick layer of moist material is practical only if the flow of air is through the layer. Conveyor belt driers are therefore almost invariably built for "through" circulation of air. Special precautions must be taken to assure uniform loading of the conveyor, and the avoidance of packing, or matting, since heavily loaded areas or those in which the product has packed tightly will fail to receive their share of the drying air and the whole conveyor will have to be slowed down to meet the abnormally slow rate of drying of those spots.

It is usual to divide the travel of the conveyor into at least two or three sections, in each of which the temperature and humidity of the circulating air may be maintained at values appropriate to that stage of the drying. The temperature and humidity of the air entering the moist layer will be substantially the same throughout the entire length of each section. This fact limits the air temperature to that which may safely be used on the driest product leaving the section. At the end of the first section, for example, there will ordinarily be a considerable gradation of moisture content within the layer, with the bottom of the layer much drier than the top; the air temperature in the entire first section must be limited to that which is safe for this driest product.

If the direction of air flow is reversed in successive sections, the gradation of moisture content within the layer may be rapidly smoothed out. Then if the material is repiled on a slower-moving conveyor, substantial uniformity of moisture content can be achieved. This repiling is desirable as a means of mixing the material prior to the final stage of drying and it may also reduce the required size of dehydrator materially. For example, potato strips piled on a conveyor in a layer about 4 inches deep may shrink to a layer less than 2 inches deep when 90 percent of the moisture has been evaporated; more than half of the total drying time will still remain to be traversed, however. At this point the product may be firm enough to be repiled in a layer 10 to 12 inches deep. If it is so repiled, the area of conveyor required for the finishing stage will be only a fifth to a sixth of that which would have been needed without the repiling.

Temperatures that are suggested as suitable for three-stage conveyor dehydrators will be found in this manual in the sections devoted to specific vegetables.

TUNNEL-AND-TRUCK DEHYDRATORS

Many different arrangements of tunnel dehydrators have been suggested, but most of them can be regarded as modifications or combinations of three arrangements: counterflow, parallel flow, and compartment (fig. 37).

Counterflow Arrangement

Figure 38 illustrates a simple counterflow tunnel dehydrator. Air flows through the tunnel in the direction opposite to the travel of moist material, so that the "hot end" is also the "dry end," and the "cool end" is the "wet end." This is the most common type of dehydrator used on the Pacific coast for drying prunes and raisins, and a number of these fruit dehydrators are being used without alteration for vege-

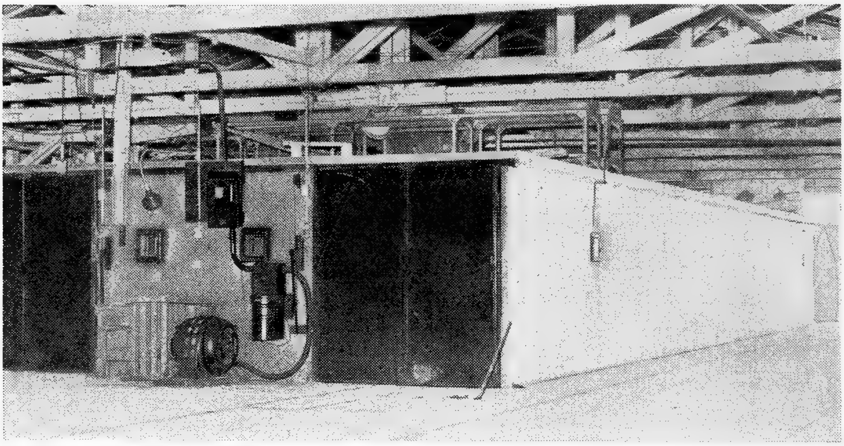

FIGURE 37.—Tunnel dehydrator.

tables. Suggested temperatures and humidities suitable for counterflow dehydrators can be found in the later section on commodities.

Since the rate of evaporation from the nearly dry product is very low, the drop in temperature of the air near the dry end of a counterflow dehydrator must be relatively slight. At the wet end of the dehydrator the product can lose moisture rapidly, but the air will be relatively cool and moist, and the evaporation rate may not be high. Figure 39 illustrates the conditions of air temperature and moisture content of product which would be fairly typical at points along a counterflow dehydrator operating at high input of wet material. Drying cannot be anything but comparatively slow near the dry end, in spite of good drying conditions, but it is also relatively slow near the wet end. Conditions like this are well adapted to the drying of fruits, but are not well suited to vegetables. Vegetables could be dried rapidly in this same tunnel by decreasing the total amount of evaporation to be done (for example, by loading trays lightly) and so decreasing the fall in temperature of the air. (See fig. 40, which may be compared with fig. 39 to illustrate the change in conditions.) In the example from which these figures were drawn the drying times were 8.2 hours to correspond to figure 39, 6.35 hours to correspond to figure 40; but the drying capacity of the tunnel was 30 percent less in the second case than in the first.

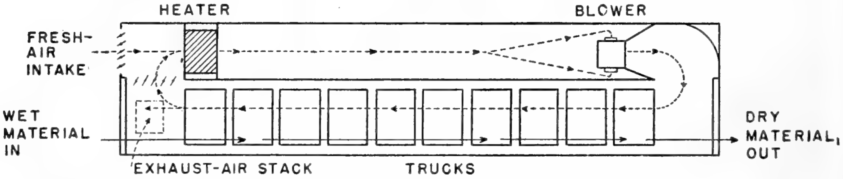

FIGURE 38.—Counterflow arrangement in the tunnel-and-truck dehydrator.

Parallel Flow Arrangement

Figure 41 illustrates the arrangement of a simple parallel-flow tunnel. The direction of air flow is the reverse of that in the counterflow tunnel; the "hot end" is therefore the "wet end," and the "cool end" is the "dry end."

This arrangement leads to a kind of exaggeration of good and bad drying conditions. At the wet end of the tunnel, where the product will lose moisture most readily, the air is hottest and driest; evaporation will be exceedingly rapid because both conditions favor it. At the dry end, on the other hand, the natural slowness of loss of moisture is reinforced by the low temperature and high humidity of the air. The equilibrium moisture content of the product will be correspondingly high. It may be impossible to reach the desired final dryness. Figure 42 illustrates the change in air temperature and moisture content through such a tunnel at high input of wet material. Under these conditions the product would not be dried below about 10-percent moisture even if the tunnel were indefinitely long.

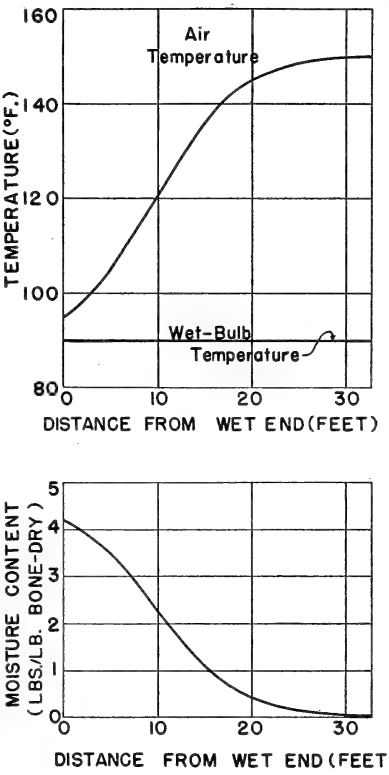

FIGURE 39.—Drying conditions in a heavily loaded counterflow tunnel drier. Time, 8.2 hours; relative capacity, 1.00; final moisture content, 5 percent.

If the rate of input of wet material to this tunnel were decreased (as by loading trays lightly), so that the fall in air temperature would not be so great, drying conditions at the dry end would not be so unfavorable. In fact, it is obvious that the performance of a parallel-flow tunnel would be indistinguishable from that of a counterflow tunnel if the air flow were so high or the amount of water evaporated were so small that little drop in air temperature occurred.

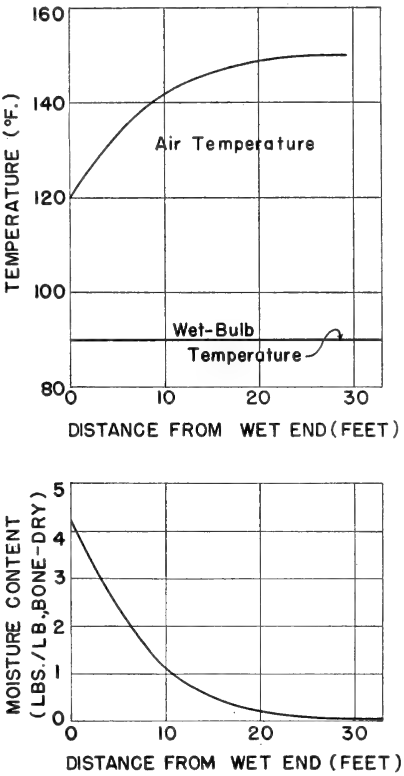

Figure 40.—Drying conditions in a lightly loaded counterflow tunnel drier. Time, 6.35 hours; relative capacity 0.71; final moisture content, 5 percent.

Combination Arrangements

The parallel-flow arrangement provides the highest possible rate of evaporation at the wet end of the tunnel, while the counterflow arrangement provides the highest possible rate at the dry end. Combinations of the two have therefore come into increasingly wide use for the dehydration of vegetables.

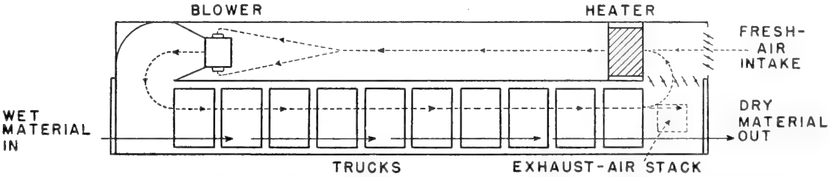

Figure 41.—Parallel-flow arrangement in the tunnel-and-truck dehydrator.

The simplest combination consists of two separate tunnels, as illustrated in figure 43. The parallel-flow tunnel may be relatively short and is designed to accomplish a large proportion of the total evaporation very rapidly, but to discharge a product which still contains as much as 50 to 60 percent of moisture. High air circulating capacity and high heat input are provided. The counterflow tunnel may be longer, but the air flow and heat input will be substantially less, since comparatively little evaporation will be required there. In some designs the air exhausted from the counterflow tunnel, being warm and still comparatively dry, is used to make up all or a part of the "fresh" air required by the parallel-flow tunnel.

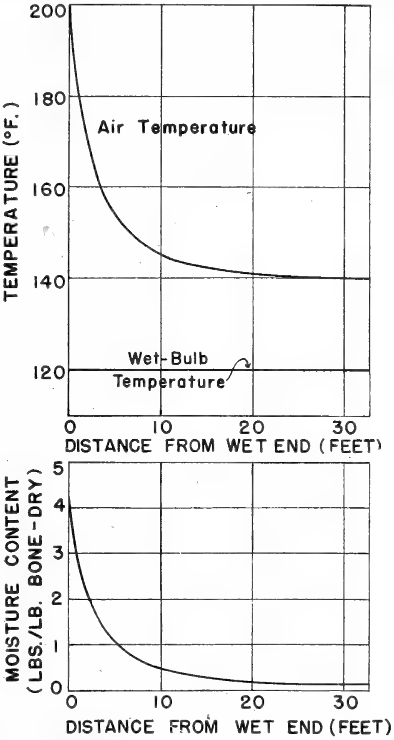

FIGURE 42.—Drying conditions in heavily loaded parallel-flow tunnel: Time, 13.4 hours; final moisture content, 10 percent.

Division of the drier into two separate tunnels necessitates an additional handling of the trucks, and therefore some increase in labor cost. Consequently there are several designs of dehydrators that combine both parallel-flow predrying and counterflow finishing into a single tunnel structure. Figures 44 and 45 illustrate two such arrangements. They are generally termed "center-exhaust"

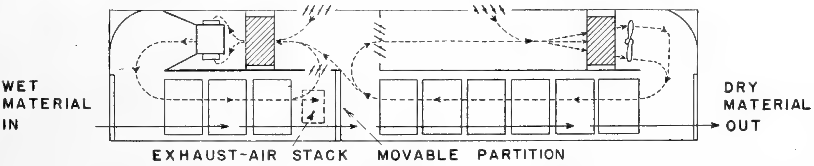

FIGURE 43.—Combination of counterflow and parallel-flow arrangements.

tunnels, since hot air flows into both ends and cool, moist air is exhausted somewhere near the center of the tunnel. Inspection of the diagrams will make it evident that whatever gain in cost of operation there may be is at least partly offset by increased complexity of construction and control.

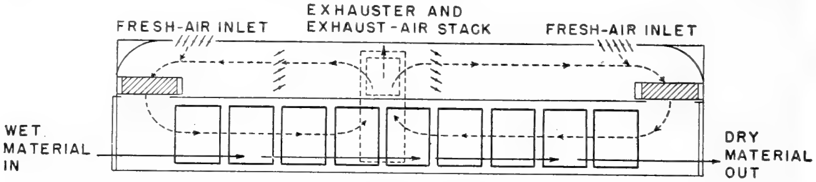

Figure 44.—Center exhaust tunnel dehydrator that combines parallel-flow and counterflow drying.

Whether the parallel-flow and counterflow sections are separate or combined in a single tunnel, the typical course of the air temperature and the moisture content of product in passing through the system are illustrated in figure 46. The maintenance of effective drying conditions throughout the entire time is reflected in rapid drying and in high capacity secured from equipment of a given size. Suggested temperatures and humidities suitable for any of these combination arrangements may be found in later sections of this manual.

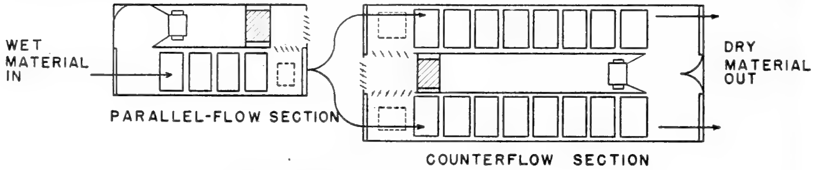

Figure 45.—Multiple-section tunnels.

Compartment Arrangement

A less common arrangement of a continuous truck-and-tray dehydrator is known as a combination compartment and tunnel. The characteristic feature is that air flow through the trucks is transverse to the long axis of the tunnel. This arrangement makes it possible to circulate the same air several times through each truck, and to reheat the air at each stage. For example, if several cabinet dehydrators (see later section on cabinet dehydrators) are placed end to end, with doors between units omitted, a truck load of wet material may start at one end of the group and progress through one compartment after another, emerging completely dry at the other end. Then if a blower is used to supply fresh air to the dry-end compartment, and air exhausted from each compartment is used to supply the "fresh-air" requirement of the next one, there is a general countercurrent flow of air through the whole group. Each compartment can be provided with a separate heater, which makes possible a wide freedom of choice with regard to air temperature at successive stages of drying. Since the air can be exhausted at high absolute humidity, good heat economy can be obtained without undue sacrifice of drying rate.

Against the theoretical advantages of this type of dehydrator must be set the fact that it is complex to build and operate. The trucks must fit very tightly into the tunnel to avoid short-circuiting of air through useless channels, and the numerous changes in direction of air flow increase the fan horsepower required and impose difficult problems of equalization of flow.

The temperature conditions suitable for successive sections of this type of tunnel are similar to those in a single cabinet dehydrator during successive equal periods of time. (See section on cabinet dehydrators.) For example, if there are six sections, the temperature in the first section must be maintained at conditions suitable for a cabinet near the end of the first sixth of the total drying time; conditions in the second section must be similar to those in the cabinet at the end of the first third of the drying time; and so on.

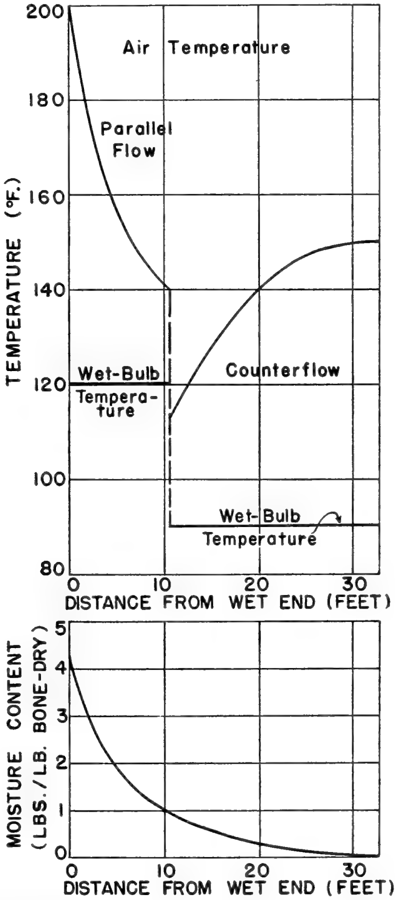

FIGURE 46.—Drying conditions in a heavily loaded combination parallel-flow and counterflow tunnel. Time, 7.6 hours; relative capacity, 1.43; final moisture content, 5 percent.

Closed-Cycle Arrangement

Any type of dehydrator can be modified so that water vapor is condensed from the exhaust air, which is then returned and used over again as "fresh" air. In this way it becomes possible to use an inert gas, such as carbon dioxide or scrubbed flue gas, without an insupportable loss of the gas. While this process, as applied to vegetable dehydration, is being investigated in several quarters, its cost and complexity have discouraged wide application. The dehumidification of the exhaust gas can be accomplished by passing it through pipes cooled externally by trickling cold water or a refrigerant, or, more simply, by direct contact of the exhaust gas with a spray of water at a temperature lower than the dew point of the gas. In the compartment type of tunnel some of this dehumidification can be accomplished in each compartment by means of a water spray in advance of the heater.

Combined Blanching and Predrying

Some development work has been done on very brief predrying at very high wet-bulb temperature, for the purpose of producing a blanching action simultaneously with the removal of a substantial part of the easily evaporated water. For example, exposure of cut vegetables to a current of air at a temperature of 250° F. or even 300°, and a wet-bulb temperature of 200° for from 6 to 10 minutes may evaporate as much as half of the total moisture, and at the same time blanch the material. While the process has interesting possibilities it has not yet reached commercial development.

STARTING AND STOPPING THE TUNNEL DRIER

Under normal conditions, the operation of the tunnel drier presents few difficulties; the beginning and ending of a dehydration run, however, require certain modifications of conditions and these are discussed below.

Simple Counterflow Tunnel

Unless corrective measures are applied, the first truckload of product introduced into a counterflow drier will be subjected to a hot, untempered blast of air during its entire time in the tunnel. Each succeeding truck, until the tunnel is filled and stabilized, will be subjected to abnormal, nonuniform drying conditions. The variation from normal drying conditions will, however, decrease as the tunnel becomes filled. As a result, the product dried during the starting-up period may be scorched and ruined.

In theory at least it is possible to schedule the drying in accordance with a predetermined time-temperature drying curve and adjust the recirculation of air to produce a constant wet-bulb temperature throughout the initial charging. The curves could be established from similar dehydrator runs or from published data or pilot tests. A typical time-temperature drying curve is shown in figure 47. This precise method is, however, impracticable, because it is impossible to adjust tunnel temperatures rapidly to the desired levels. Theoretically, as many temperature adjustments should be made as there are cars in the tunnel.

Either of two approximate methods can be used satisfactorily. With one method trucks are introduced into the drier at a faster rate than is normal, and the time interval between trucks is progressively increased until normal operating conditions are reached. Although the method produces fairly uniform drying, it is limited in application. For instance, a plant with a large number of driers will be faced with a formidable scheduling and coordinating problem. In order to keep up with the initial demand, the processing line must be speeded up temporarily, or the prepared product must be accumulated over a period of time. If this first expedient is impossible, a second may be used. This method consists of the application of a modified drying schedule, and produces acceptable results. It is apparent from figure 48 that the greatest drop in dry-bulb temperature occurs at the wet or loading end of the drier. Therefore, in modifying the temperature schedule, most of the adjustment should occur during the initial stages of the starting-up period. With this as the basis and by reducing the number of temperature adjustments to a minimum, a rough approximation of the time-temperature curve is established as shown by the dotted graph. Since the drying curves for all products are basically similar in shape, this simplified graph can be used in starting most counterflow dehydrators. The success of

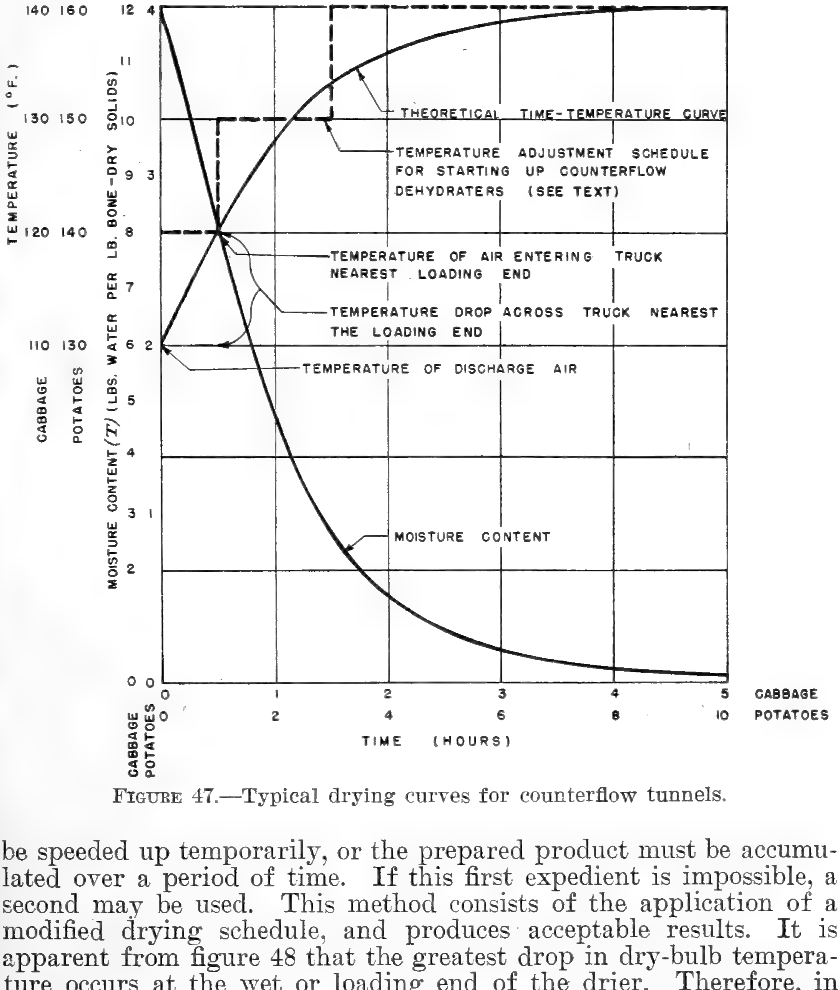

Figure 47.—Typical drying curves for counterflow tunnels.

this method is predicated upon accurate estimation of hot- and cold-end temperatures.

In preparing a schedule, a suitable hot-end dry-bulb temperature is selected and a cold-end temperature is computed or estimated. (See section on principles of dehydration.) A normal retention time is estimated, based on past performance; this time is the same as that required to fill the tunnel under normal scheduling. The initial charging temperature is then located on the curve as equal to the expected cold-end temperature plus a third of the expected over-all tunnel-temperature drop. A second control point is similarly located on the curve in a position corresponding to a lapse of 10 percent of the retention time. The temperature at this point will be equal to the initial charging temperature plus another third of the difference between the expected hot-end and cold-end temperatures. Similarly a third point is spotted at a time position corresponding to a 30 percent lapse of the retention time. At this point, the tunnel temperature is brought up to full normal hot-end dry-bulb temperature.

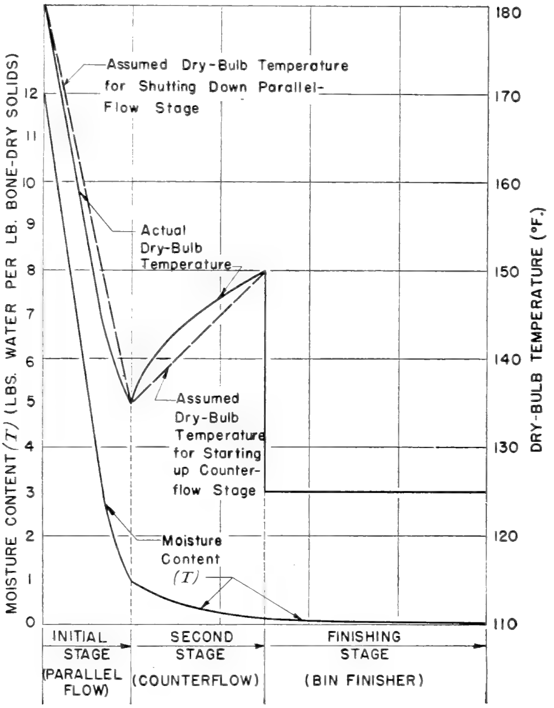

Figure 48.—Typical drying curves for multistage dehydration.

In operation this seemingly complicated program is easily carried out. For example, consider a 10-truck counterflow dehydrator being used to dry potatoes. Previous runs under similar conditions indicate that the drying time will be approximately 10 hours when the hot-end temperature is 160° F. and the cool-end 130°. The initial temperature should therefore be $130^\circ+(160^\circ-130^\circ/3)$ or 140°. At the end of one hour—that is, after 10 percent of the estimated drying time has elapsed—the set temperature is raised to 140° + (160° − 130°/3) or 150°. At the end of 3 hours, corresponding to 30 percent of the estimated drying time, the temperature is again raised to the normal hot-end dry-bulb temperature, 160°.

During this starting-up period, loaded trucks are introduced into the drier at their normal rate. The wet-bulb temperature within the drier should be maintained at or near its normal operating value. This means that a large proportion of the air must be recirculated at the beginning, decreasing in amount as more trucks are introduced.

Ending a run on a counterflow tunnel dehydrator normally does not present any difficult problems. The only effect of terminating the supply of raw product is a gradual decline of the wet-bulb temperature. This condition will probably not result in injury but will carry the product to a lower moisture content than desired. To prevent this, the recirculation damper should be readjusted to maintain normal wet-bulb conditions. This may also be accomplished by speeding up the removal of the final trucks or slightly lowering the tunnel temperatures.

Parallel-Flow Tunnels in Multistage Driers

The parallel-flow tunnel is never used as a single-stage vegetable dehydrator, because of its poor drying characteristics at the finishing end. Therefore it will be considered only as one stage of a multistage dehydration unit. The product is usually dried in that stage to a moisture content of about 50 percent ($T = 1.0$). For various products, this would correspond to removal of 75 to 93 percent of the original moisture and hence, if we were to refer to the time-temperature drying curve as shown in figure 48, the range would be confined to the fairly steep part of the curve which indicates the relatively rapid drying range.

In starting up a parallel-flow tunnel, the hot-end tunnel temperature is brought up to normal operating temperature, and then the loaded trucks are placed in the tunnel on the normal operating schedule. For temperature-sensitive products and especially those that are susceptible to case hardening, care should be exercised by the operator to adjust the recirculation damper so as to maintain normal operating wet-bulb conditions. During the initial loading, the drying load is light. Hence, greater than normal recirculation must be practiced to keep the wet-bulb temperature at a reasonably high level or else the product may be permanently injured as a result of excessive drying of the outer product surfaces.

When operation is to be stopped, care must be exercised to prevent damage due to excessive drying and scorching. When a run is ended and filled trucks are replaced with empties, the wet-bulb temperature will begin to decline if countermeasures are not taken. This is occasioned by the decrease in drying load. The dry-bulb temperature, being automatically controlled, will remain constant; hence, the last filled car will be subjected to a constant high temperature and a continually falling wet-bulb temperature during its passage through the tunnel. The effect, unless controlled, will be to produce higher and higher drying rates within each successive car of the last tunnel load. Scorching, discoloration, case hardening, and other injury may result. At best the product will not be uniformly dried.

Adjustment is carried out in the following manner. The hot-end dry-bulb temperature is decreased, to simulate normal drying conditions. This is achieved by dropping the hot-end temperature in successive steps equal to the average temperature drop across a truck each time an empty truck is placed in the tunnel and until the unit is emptied of all products. The average temperature drop across the truck may be computed by dividing the difference between the hot-end and cold-end tunnel temperatures by the number in the tunnel. Similarly, the wet-bulb temperature can be maintained substantially at a constant level by adjustment of the recirculation damper as each succeeding truck is removed. By reference to figure 48, it will be noted that a straight line between the upper and lower temperatures in the parallel-flow drying range will not be at great variance from the curve that represents temperature. This fact suggests the reliability of the method.

Counterflow Tunnel as Second-Stage Drier

In multistage dehydration, the counterflow tunnel is almost invariably used as the secondary or intermediate stage. The entering product has been predried and usually contains about 50 percent moisture ($T=1.0$). There is little danger of case hardening; therefore exposure to normal dry-end tunnel temperatures over prolonged periods of time will result only in drying to lower moisture levels, approaching the equilibrium point as a limit.

Since the moisture removal in a secondary stage is comparatively small, the temperature drop in the tunnel is also small. Thus, when the predried product is first placed in the counterflow tunnel, which has been brought up to normal operating temperature, the product will be subjected to a temperature slightly higher than the average for its normal retention time. The result will be a satisfactory product that has been slightly overdried. In the event that exceptional operating precautions are required with a temperature-sensitive product, the procedure previously outlined for the counterflow tunnel operation can be used. For most if not all products, this procedure will be found unnecessary.

No special precautions are suggested for shutting down a counterflow secondary drier. It is operated at normal temperatures until the product has been cleared from the tunnel. Some fuel may be saved by readjustment of the recirculation damper to maintain normal wet-bulb temperatures. Here again, it is possible to shorten the retention time of the last trucks as a means of preventing excessive drying.

CABINET DEHYDRATORS

Cabinet driers serve two main functions: (1) In single or multiple units they are suitable for capacities such as 1 to 20 tons of fresh vegetables per day, and particularly when different vegetables are to be handled at the same time, and (2) they are useful for pilot-scale and experimental operations as a means of obtaining drying rates and other data applicable to tunnel drying.

Batch dehydrators, of which cabinet driers are an example, thus have a special field of usefulness quite distinct from that of continuous dehydrators. Batch driers can be built as small as desired, for community, institution, farm, or even family use. Since the drier can be shut down completely when a batch has finished drying, it is well adapted to daytime or one-shift operation. Continuous driers, on the other hand, require a number of hours to start up and shut down, and hence are best adapted to continuous, three-shift operation. The purpose here is to describe several types of cabinet driers and to discuss in greater detail suggestions for the operation of these cabinets as single and multiple units.

A typical cabinet dehydrator consists of an insulated structure, square or rectangular in shape, equipped with a fan that forces the drying medium (usually air) through a heating system and distributes it uniformly through one or more stacks of trays loaded with prepared material. The walls and top can be constructed from a number of materials such as plywood, masonite, transite, brick, or hollow tile. Inflammable materials should be adequately protected around the heating system, particularly if the latter is of the open-flame type. Duct turns, baffles, or other means are provided to insure proper distribution of the heated air and thus prevent uneven drying. Adjustable dampers are provided to admit fresh air and to exhaust the moist air. By proper adjustment of the damper a definite percentage of the moist, hot air can be recirculated as a means of conserving fuel, and in addition a control is maintained over the degree of humidity in the cabinet. Dry-bulb and wet-bulb thermometers are mounted on the exhaust side of the cabinet and a dry-bulb thermometer on the intake side.

Cabinet dehydrators differ in the manner used to heat the air and in the method used to circulate and distribute this heated air through the loaded trays. Some are heated by the combustion of natural gas directly in the circulating air, and under controlled conditions some grades of fuel oil can be similarly used. Others are heated by fin-type steam coils or iron-pipe radiators, whereas still others are equipped with one of several types of heat exchangers and are heated with gas, oil, coal, coke, or wood as fuel. With direct-burning gas or oil heaters, most of the heating value is utilized, whereas in the indirect heat-transfer systems, only 50 to 75 percent of the heating value is made available. In any case, the heating system should be of such capacity that it will supply to the circulating air from 1,200 to 1,600 B. t. u. per hour per square foot of active tray surface used in the cabinet. A common error is the installation of a heater of insufficient capacity. The actual capacity of the heating unit will depend on a number of factors, such as amount of insulation in the cabinet, air flow, temperature ranges desired, degree of recirculation of the air, and the load to be dried. Most cabinet dehydrators are equipped with centrifugal or rotary fans, of which there are many types; others employ one- or two-blade propeller or radial fans. These fans should be of such size and should be driven at such speed as to deliver an air velocity, measured between the loaded trays, of 800 to 1,000 feet per minute.

The prepared vegetables are spread on suitable trays made from either metal or wood with bottoms of hardware cloth. All-wood trays are also used. The trays are usually of two sizes—a two-man 3 by 6-foot or the one-man 3 by 3-foot size. The loaded trays are stacked one above the other, either by sliding them in on guide rails arranged in a metal frame on a movable truck or by stacking them directly on top of each other on the truck without any support. In the smaller cabinets, individual trays are placed on guide rails one above the other. The free opening between trays should be 2 to 3 inches.

Types of Cabinet Dehydrators

To illustrate more clearly how these various parts are assembled to form a cabinet and how they function, brief descriptions of several types of cabinet dehydrators are included. Perhaps the most common type of cabinet drier is one similar to the design in figure 49.

This cabinet is equipped with two or three centrifugal fans mounted on a single shaft and propelled by one motor. Air is forced through the fin-type steam coils and distributed through the trays by means of adjustable louvers. Unless duct turns, baffles, or adjustable louvers are provided in this type of cabinet, most of the heated air will be forced through the bottom row of trays. Dampers are provided to control the amount of recirculation of air and the degree of humidity in the cabinet.

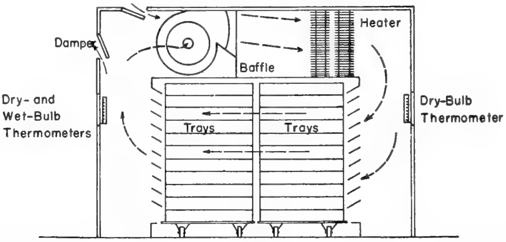

FIGURE 49.—Cabinet dehydrator equipped with centrifugal fans and steam-heated fin-type coils.

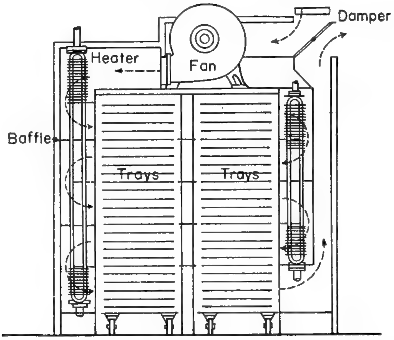

FIGURE 50.—Cabinet dehydrator designed to reheat the air in stages.

The cabinet dehydrator illustrated in figure 50 is designed to reheat the circulating air in several stages, rather than all at once as in the design shown in figure 49. Fresh air is drawn through the intake damper, picked up by the centrifugal fan, and forced through the left-hand steam coil in the first stage of heating. Partitions are so placed that the heated air passes through a few trays at the top of the truck, then through the heater on the right-hand side, and back through another section of trays as indicated by the arrows. The moist air comes through the bottom row of trays and is carried through a duct to the exhaust damper at the top of the cabinet. Recirculation and humidity control are maintained with this damper. Two advantages are claimed for this design: (1) By repeated heatings fewer pounds of air are necessary to remove a given weight of water, and (2) more moderate dehydrating temperatures can be used.

More recently several cabinet dehydrators equipped with propeller-type fans have been designed. One of these designs, which was developed for use by State and Federal institutions, is illustrated in figure 51. Double-walled sides and top are made up in such a manner that the sections can be bolted to form a portable unit, and these sections are insulated to prevent excessive heat losses. A four-blade, laminated-wood propeller, 5½ feet in diameter, is driven at 600 r. p. m. to deliver 800 to 1,000 feet of air per minute as a suction air flow. Four sets of stationary duct turns are installed to insure a uniform air flow through the trays. Steam-heated fin-type coils or iron-pipe radiators make ideal heating units for this type of cabinet, although direct gas heaters can be used also. An intake-exhaust damper is provided for air recirculation and humidity control. Slanting trays may be used to direct the air down through the food material rather than horizontally across it.

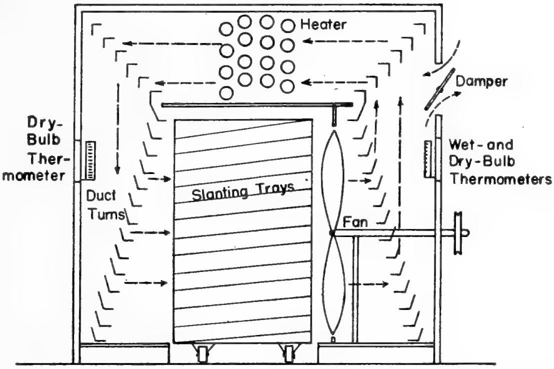

FIGURE 51.—Cross-blower cabinet dehydrator employing airplane propeller.

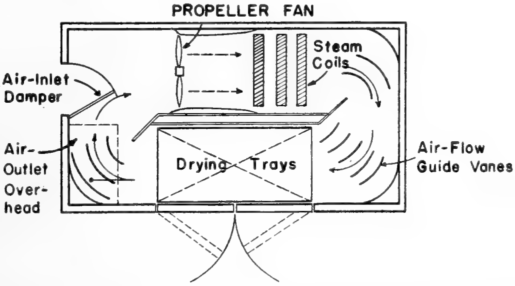

FIGURE 52.—Steam-heated single-truck cabinet dehydrator.

If trucks fitted with guide rails are used, the rails can be so arranged that the trays are slid into the truck in a slanting position. If the trays are to be stacked one on top of the other, the screen bottoms can be built into the wood frames in a slanting position.

With another type of cabinet dehydrator, which uses a propeller fan, an entirely different method of air distribution is utilized, as illustrated in figure 52. The propeller is mounted on one side of the cabinet directly behind a steam-heated fin-type coil. The air flow is heated by means of the steam coil and forced through a series of curved guide vanes at one end of the cabinet. The air travels through one or more stacks of trays and is turned back toward the fan by means of another series of similar vanes at the opposite end of the cabinet. Suitable dampers are provided for air recirculation and humidity control.

Preparation Equipment for Use With Cabinet Driers

The amount of preparation equipment required depends on the extent of operation. For small batches, hand preparation methods can be used, but if several runs of 500 to 1,000 pounds of prepared material are to be made each day, then supplementary preparation equipment will be required. It will be necessary to set up a regular preparation line for the handling of 15 to 20 tons of raw material per 24 hours in a series of cabinets.

In general the following procedure may be used with a single-cabinet dehydrator. Fresh vegetables are prepared and properly blanched. For small-batch operations where a limited supply of steam is available, a cabinet-type steam blancher holding 3 or 4 individual trays can be conveniently used. The loaded trays are slid into the cabinet one above the other on supports made from several pieces of perforated pipe, all connected to the steam supply.

After loading, the steam is turned on and the blanching time started after the temperature around the trays has reached 200° to 212° F. One or more trucks of trays loaded with the prepared and blanched vegetables, or individual trays in the small units, are pushed into the cabinet, the doors fastened, and the fan and heater started. It is good practice to preheat the cabinet in order to cut down on the time required for the temperature to gain its maximum point after loading. The heating capacity should be high enough to maintain the dehydration temperature at the desired point when the load of wet material is placed in the cabinet.

Operation of the Cabinet Drier

The proper adjustment of the intake-exhaust damper must be determined by experience with a particular type of cabinet dehydrator. and with the products to be dried. In most cases it will be necessary to close the damper at the beginning of the drying process in order to allow the inside temperature to reach the desired point as quickly as possible after loading. The damper should then be opened and adjusted to give a high rate of fresh-air intake with little or no recirculation, in order to remove the water vapor as rapidly as possible. High dry-bulb and low wet-bulb temperatures are maintained to dry the product in the shortest length of time. At this point the large-capacity heating unit is a necessity in order to insure the maintenance of a high dry-bulb temperature. The rate of drying will be very rapid at first because of the high rate of water evaporation from the product, large air circulation, high temperature, and low humidity. As drying progresses, the rapid evaporation of water is materially reduced, being replaced in part by a slow diffusion process. When this takes place, less heat and air circulation are required, and the damper can be partly closed to increase the amount of recirculation and thus avoid excessive heat losses. As the damper is closed, the dry-bulb temperature on the intake side should be lowered in steps and the drying finished off at temperatures of 120° to 170° F., varying with the product, to prevent scorching.

It should be understood that when temperature or absolute humidity of the fresh-air supply changes, both the heat supply and the setting of the dampers must be varied accordingly if a desired temperature schedule is to be maintained. For example, if the temperature of the fresh air supply is lowered, the heat input must be increased to maintain the desired cabinet temperature. If the absolute humidity of the fresh air rises, the amount of recirculation must be decreased and additional heat must be supplied, since an additional quantity of fresh air must then be heated up to cabinet temperature. If temperature and recirculation are controlled automatically, these compensations will be made by the mechanism.

During the dehydration process most of the water is removed from the product during the first 2 hours, and the last portions are the hardest to remove. Two methods can be used for equalizing the final moisture content of the material. If single batches are used each day, the simplest method is to leave the material on the trays in the cabinet and continue the dehydration overnight, after lowering the temperature to 120° to 125° F. and running the circulating fan at a reduced speed. This practice is somewhat costly. If it is desired to run the single cabinet continuously, then a small-capacity equalizing bin is useful. The contents of the trays are dumped together into this bin, the top is partly closed, and air heated to 120° to 125° (wet-bulb not over 75° to 80°) is forced up from the bottom and through the material to carry off the remaining moisture.

Continuous Dehydration in Cabinet Driers

Several continuous systems of dehydration have been developed by the use of a series of two or more cabinet driers for handling 10 to 20 tons of fresh material per 24 hours, and even higher in some cases. (See discussion of compartment arrangement, p. 82.) One design employs a battery of four duplex cabinet dehydrators. These duplex units are placed side by side in line, each fitted with two sets of doors so that the trucks go in at the front and out at the back. Each unit consists of two independently controlled air-conditioning systems, one to provide optimum primary conditions for dehydration, the other to provide optimum finishing conditions. These independent systems make it possible to maintain two temperature ranges in the same unit without the use of partitions. The primary chamber is designed to give extremely rapid drying by the use of high temperatures and air velocity during the period when the material is still wet. The finishing chamber is designed to remove the remaining moisture from the material at such temperatures as will not cause scorching or other damage.

In a suggested operation procedure, two trucks are loaded with the prepared and blanched material and pushed into the primary chamber of the first cabinet, and this is repeated for each unit. Initial dehydrating temperatures of 180° to 190° F. are used, and the temperature is gradually reduced to 160° during the first 2 hours of drying. The two trucks are then moved over into the finishing chamber for an additional 2 hours of drying at a temperature range of 160° down to 145°. Two newly filled trucks are pushed into the empty space in the primary chamber, and this procedure is repeated in each unit. At the end of the dehydration period, the trucks are removed from the finishing chamber and the dried product equalized in moisture content in a finishing bin, and then packaged.

Establishing a Time and Temperature Schedule for Cabinet Dehydration

As drying in a cabinet progresses it is necessary to lower the dry-bulb and wet-bulb temperatures by steps until the appropriate finishing temperature is reached. These changes in temperature should proceed in accordance with a schedule that must be determined by experimental pilot tests. Each schedule is of course applicable only to uniform conditions of air flow, tray loading, and shape and size of pieces.

Since it is usually impractical to make moisture analyses of the product as drying progresses, changes in moisture content can be estimated by weighing at frequent intervals. The temperature changes are made when the reduction in weight reaches certain values determined by multiplying the estimated dry weight of the product by the factors indicated in table 8 for each product.

At least two pilot tests are required to establish a time schedule for temperature change as dehydration progresses. The first provides an estimate of the amount of water lost from the product during dehydration, or conversely the yield of dry product from prepared. This is accomplished by loading the drier with prepared material, recording the weight on one or more trays, drying under constant temperature at or near that suggested as finishing temperature for the product, and recording the weight and percentage of yield of dry product.

Let us assume that the drier has a capacity of 1,000 pounds of prepared potatoes and that it is provided with three trays that can be readily removed for weighing. One of the trays is located halfway between the top and middle, one in the middle, and one halfway from the middle to the bottom of the tray stack. When the cabinet is fully loaded, it is found that the net weight of product on each of the three trays is 20 pounds and that after dehydration at 150° F. dry-bulb and 90° wet-bulb the average weight of the trays of product is 4.2 pounds. Then the yield of dry product is 21 percent.

The second pilot test is made to determine the time schedule for reducing the temperature during the regular run and is carried out as indicated in the following example: The cabinet is loaded with 1,000 pounds of prepared potatoes. The three trays mentioned above are each loaded with 20 pounds of raw material. In the first test it was determined that the drying yield for these potatoes was 21 percent, so that from each of the trays a yield of $0.21 \times 20 = 4.2$ pounds of dry material can be expected. Dehydration is started at 200° F. dry-bulb and 120° wet-bulb temperature. At frequent intervals the trays are weighed. When the average weight of a tray of material drops from 20 to 3 times the expected dry weight, or 12.6 pounds, the time for this drop in weight is recorded and the temperatures dropped to 170° F. dry-bulb and 105° wet-bulb as indicated in table 8. When the average weight is reduced from 12.6 pounds to 2 times the expected dry weight or 8.4 pounds, the time for this drop in weight is recorded and the temperature dropped to 155° dry-bulb and 95° wet-bulb as indicated in table 8. The time required for the weight of the product to be reduced from 8.4 to 1½ times the expected dry weight or 6.3 pounds is

Table 8.—*Suggested dry-bulb and wet-bulb temperature changes for cabinet dehydration pilot run*

Vegetable	Original weight reduced to number of times dry weight [1]	Dry-bulb temperature drop	Wet-bulb temperature drop
		°F.	*°F.*
Potatoes	3	200–170	120–105
	2	170–155	105–95
	1.5	155–150	95–90
		150	90
Sweetpotatoes	4	200–175	120–110
	3	175–170	110–105
	2	170–160	105–95
		160	95
Onions	6	165–155	100–95
	4	155–145	95–90
	3	145–140	90–85
	2	140–130	85–80
		130	80
Carrots	4	200–180	120–110
	3	180–160	110–100
	2	160–155	100–90
		155	90
Rutabagas	4	200–180	120–110
	3	180–160	110–100
	2	160–150	100–90
		150	90
Beets	4	200–175	120–110
	3	175–155	110–105
	2	155–150	105–90
		150	90
Cabbage	6	165–160	100–95
	4	160–150	95–90
	3	150–140	90–85
	2	140–135	85–80
		135	80
Celery	6	165–155	100–95
	4	155–150	95–90
	3	150–135	90–85
	2	135–125	85–80
		125	80
Spinach	3	200–185	120–115
	2	185–180	115–110
	1.5	180–170	110–100
		170	100
Tomatoes	3	200–175	120–110
	2	175–150	110–90
		150	90
Sweet corn	3	180–170	110–105
	2	170–165	105–95
		165	95
Snap beans	3	180–165	110–100
	2	165–155	100–95
	1.5	155–150	95–90
		150	90
Peas	3	180–160	110–100
	2	160–155	100–95
	1.5	155–150	95–90
		150	90
Lima beans	3	180–160	110–100
	2	160–150	100–90
		150	90
Parsnips	3	200–175	120–110
	2	175–165	110–100
	1.5	165–160	100–95
		160	95

---

[1] Dry weight=expected dry weight as determined in first pilot run.

recorded, and in accordance with table 8 the dry- and wet-bulb temperatures are lowered to 150° and 90° in the order named. Dehydration is then continued at these temperatures until complete.

Suppose that the second test gave the following results:

Reduction in pounds:	*Time in minutes*
20 to 12.6	42
12.6 to 8.4	33
8.4 to 6.3	25
6.3 to completion	250

The time schedule for temperature changes would then be established as follows:

Minutes from start:	*Temperature changes (°F.)* *Dry bulb*	*Temperature changes (°F.)* *Wet bulb*
42	200 to 170	120 to 105
75	170 to 155	105 to 95
100	155 to 150	95 to 90

During the second pilot test the product should be inspected for evidence of scorching. If scorching occurs, the operator will be able to adjust the temperature change in other pilot runs, which will be necessary to determine suitable conditions. Let us assume that it was observed that scorching occurred within 42 minutes from the time of starting. This would indicate that the first lowering of temperature should be made sooner but that the temperature should not be lowered as much as shown above. Another pilot test would be run in which the first break in temperature would be made, for example, at the end of 20 minutes, from 200° to 185° F., then at the end of 42 minutes from 185° to 170°. On the other hand, suppose that it was observed that scorching occurred in the time range from 100 minutes to completion of drying; then another pilot run would be set up in which a lower finishing temperature, for example 145°, would be used.

Because of the lack of complete knowledge it is difficult to set up systems of temperature change in cabinet dehydration. Each operator must depend upon the method of trial and error and experience. The method discussed above is offered for the purpose of supplying a starting point for such investigations. It should be remembered that the conditions suggested may not in all cases give the best results.

SOURCES OF HEAT FOR DEHYDRATORS

Two general systems are commonly used to heat dehydrators: The direct-combustion heater and the indirect heater. With the former, the fuel is burned inside the dehydrator and the gaseous products of combustion are circulated along with the drying air. With the indirect system, auxiliary heating surfaces for transferring heat to the drying air are used. The latter completely isolate the products of combustion from the drying air and hence complete combustion is not essential, so far as the product is concerned. Fuel-oil burners should be installed in accordance with the recommendations of the National Board of Fire Underwriters.

Direct-Combustion Heaters

Direct heaters are limited to liquid or gaseous fuels. The rate of combustion of these fuels can be readily controlled over a wide range and thus temperature can be controlled. Obviously, complete burning is essential with the direct heater, especially with oil, because imperfect combustion might result in smoking, which would seriously affect quality of product. Since there are no stack or transmission losses, optimum efficiency can be obtained, and a minimum of equipment is required for satisfactory performance. Most of the dehydrators on the west coast use this system.

In its simplest form, the heater consists of a "premix burner" located openly in one of the air passages of the dehydrator. The intensity of flame and hence the dehydrator temperature can be controlled by a manually operated globe valve placed in the fuel supply line. This simple system, however, has many limitations. Temperature regulation is tedious and combustion efficiency is likely to be poor. Close temperature regulation, however, can be accomplished by substituting a modulating control valve for the manual control valve. (See section on controls.)

A basic rule, applicable with any fuel, is that combustion should occur in a relatively high temperature zone with a minimum of chilling from outside. If an open gas flame is exposed to an air stream of relatively low temperature, the partially burned gases in the outer surface of the flame may be chilled below the ignition point and swept away, with a resulting decrease in the efficiency. Fuel oil, especially the heavier grades, cannot be satisfactorily burned in an open flame, because the chilling effect of the surrounding air currents will cool the burning oil particles below their ignition point, and smoking will result.

A satisfactory way of burning either gas or oil is through the use of a combustion tube. This device consists essentially of a refractory-lined chamber of ample proportions to permit generation of the maximum heat required while the flame is confined to the combustion chamber. In the design of the chamber and burner, care must be taken to prevent direct impingement of flame on refractory lining, as this might result in either damage to the refractory or, with oil, the formation of coke-cones, with consequent smoking.

Figure 53 shows a direct-combustion heater suitable for use with either gas or oil. It will be noted that a refractory checker brick partition divides the space into a primary and a secondary zone, and serves as a screen to confine the radiant heat to the primary zone. When operating, this zone reaches incandescent temperatures—a desirable condition for gas combustion and an essential feature for complete, smokeless oil combustion. The checker screen serves as a baffle to prevent the escape of unburned oil droplets. Impingement of the droplets on the incandescent screen will result in surface combustion.

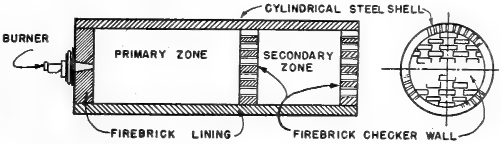

FIGURE 53.—Direct-combustion heater.

The secondary zone is an added precaution, desirable as a combustion aid, not essential with gaseous fuels, but necessary as an assurance against smoking when oil is used. Large unburned particles of oil that escape from the primary zone will burn at an accelerated rate when they come into contact with the high-velocity, high-temperature gases flowing through the checker wall restrictions. The particle is then given additional time in the secondary zone to burn completely before coming in contact with the drying air. Without the secondary zone, smoking might result.

Because the products of combustion are to be mixed with the drying air, any amount of air necessary for complete combustion in direct heaters can be used without impairing the efficiency of the system. This factor is especially important with oil, because oil requires a considerable amount of excess air to insure complete combustion and thus prevent smoking. As a rule, heavy oil can be completely burned with 250 percent of excess air. More than this amount of air may chill the flame and produce deleterious effects. The design of the secondary air opening varies with the burner used and should be provided for in accordance with the manufacturer's recommendations.

Indirect Heating System

Indirect heating systems can be divided into two general types. First, and simplest from the standpoint of equipment, are those with heat-exchange surfaces receiving heat directly from flue gases or products of combustion. The second, a somewhat more complicated type, employs a medium such as a liquid or vapor to transfer heat from its source to the heat-exchange surfaces.

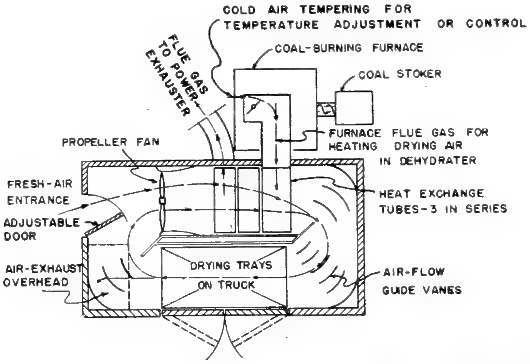

FIGURE 54.—Coal-burning, single-truck cabinet dehydrator.

The first type, as one might expect, is inefficient and difficult to control. It can, however, utilize a variety of fuels. Temperature regulation is difficult even when gas or oil is used. However, complete combustion is not essential for successful performance of the indirect-heated dehydrator. Some smoking can be tolerated, because the products of combustion do not come in direct contact with the drying air.

If coal or wood is used with this system, a fair degree of control can be obtained by either wasting some of the products of combustion to atmosphere before they come in contact with the heat-exchange surfaces, or by diluting and cooling the flue gases with outside air prior to their flowing over these surfaces. Obviously these methods of control are wasteful. Although this type of indirect heating has its applications, it is of little value in commercial use. A typical example of a small unit employing this system of heating is shown in figure 54. This unit employs an automatic coal-fired stoker.

The second type of indirect system, on the other hand, offers practically ideal control characteristics. The heat-transfer medium is usually steam, but may be hot water or oil. This method of heating offers a clean, even source of heat with any type of fuel, either liquid, solid, or gaseous. The boiler or accumulator is a source of heat that can be used instantaneously to cope with variations in demand. Regulation of temperature within the dehydrator can be accomplished by a relatively simple method, which is applicable over a complete range of dehydrator sizes. On the other hand the equipment is considerably in excess of that required by other methods, and the over-all efficiency is considerably below unity because of boiler and transmission losses and will in all probability be less than 60 percent. Initial cost, upkeep, and overhead are correspondingly high.

Heat exchange surfaces are normally copper-finned coils. Relatively large amounts of heat can be transferred to air in motion by a compact heat-exchange surface of this type. However, because of wartime restrictions, copper heating coils cannot be procured at this time and, as an alternate, steel-finned coils are being manufactured. Their procurement is difficult, and the operator may find it expedient to improvise some other surface, such as steel pipes arranged to form a suitable coil. The amount of unfinned pipe required to effect a given heat transfer will be considerably in excess of that required for finned pipes. The size of coil thus formed might well exceed the normal space usually allotted to the heating unit, and may therefore be a limiting factor in the design of the steam-heated dehydrator.

A second limitation would be an increase in static pressure caused by pipes or coils, which must be overcome by the fan or blower. To keep the face velocity of the air and hence the static pressure down, the pipes must be properly spaced.

If a coil is to be built for use in a dehydrator, it is suggested that care be taken in the design to provide ample surface for adequate heat transfer, because the performance of the dehydrator is at stake. Rapid and complete elimination of the condensate and air is also necessary to promote coil efficiency.

Some large steam-heated dehydrators have been successfully designed to use steam for driving the blowers and to utilize the exhaust steam in the heating system. The blowers are driven by bleeder-type turbines, operating at a back-pressure of from 10 to 50 pounds per square inch. Such an arrangement may reduce power costs very considerably. Each turbine may be designed and operated so that the steam flow through it will normally be less than the minimum steam demand of the corresponding heaters, so that additional high-pressure steam will always have to be bled into the heating system. Automatic controls will then adjust the auxiliary steam supply to satisfy the heater demand without affecting the operation of the blower.

TEMPERATURE CONTROLLERS

There are two general basic types of temperature controllers—the off-on controller and the modulating controller. The choice between these two is determined by the type of heating system used in the dehydrator. Essentially, the piping arrangement is the same and is independent of the type of controller used, as well as the kind of fuel or heating medium employed. (See figure 55 for a typical arrangement.)

As its name implies, the off-on controller operates a motorized valve in such a way that it is either fully opened or fully closed. There is no intermediate valve position. For this reason, all off-on controllers are essentially instruments with high sensitivity. This type of controller is relatively simple to operate, and is inexpensive. It is available as an air-, electric-, or direct vapor-operated instrument. Features such as indicating and recording devices can be included and are desirable for use on vegetable dehydrators.

The modulating controller is more complicated than the off-on type and is available as an air- or electric-operated unit. Because of its comparative ease of adjustment and its ability to transmit a modulating force to the motorized valve, the air-operated instrument dominates.

In modulating controllers, action is imparted to the motorized valve in such a way that the valve-stem movement is proportional to the difference between the actual tunnel temperature and the set temperature on the controller. Instruments vary in sensitivity—that is, they vary in the amount of movement of the indicating pointer required to cause the motorized valve to change from a fully opened to a fully closed position. Sensitivity is measured in degrees required for maximum valve opening. Thus, if the temperature required for full opening of the valve is at wide variance with the set temperature, then the instrument is said to have low sensitivity. Conversely, if the variance is close, the instrument is said to have high sensitivity. If the sensitivity of an instrument were carried to its ultimate, it would become an off-on instrument.

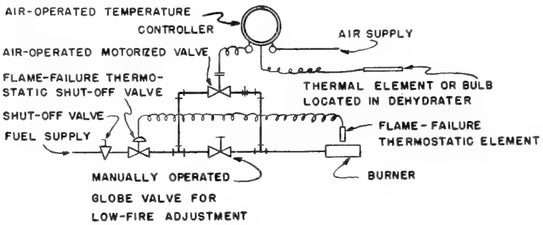

FIGURE 55.—Typical simplified burner control diagram.

Sensitivity should not be confused with instrument response. Response of an instrument is the ability of the thermal element to transmit temperature variations to the controller. It is assumed in subsequent discussion that the thermal-element temperature response is the same regardless of the type of controller used. Most instruments incorporate means to permit change of sensitivity. The need for this variable-sensitivity device will be discussed in more detail.

Every heating system, whether it is for a tunnel or a cabinet dehydrator, a bin finisher, or a lye vat, has an inherent characteristic that must be fully recognized before an automatic temperature controller can be properly selected. Generally, if the temperature response of the system is rapid, the controller should be of the modulating type; if it is sluggish, the controller can be either the off-on or sensitive modulating type. In the latter case, the off-on controller, being the less costly of the two, is generally used. In order to illustrate these general rules, the temperature-control problems of several different heating systems will be analyzed below:

Suppose that a counterflow tunnel is being used as a finishing drier for onions and that it is being heated by an open gas flame. What type of controller should be provided? Temperature regulation for onions is critical. Excess temperatures may cause discoloration of the finished product, whereas low temperatures retard the drying. For optimum conditions, the dehydrator should be operated at the highest permissible temperature that can be controlled within close limits.

Because of the small heat inertia of the open-flame method of heating, the use of an off-on controller would be unsatisfactory. Upward variations in flame intensities are immediately manifested by increase in tunnel temperatures. With extreme care in operation, the manually operated globe valve (fig. 55) can be opened to maintain a low-fire condition, so that the resultant flame, without action from the temperature controller, will produce a temperature within the tunnel only a little lower than the set temperature. The off-on controller may then be relied upon to admit periodically additional fuel to bring the average tunnel temperature to the desired condition. However, because of the low heat inertia of the heating system, even a diminished fluctuation of fuel flow may permit the temperature to fluctuate so widely as to scorch the onions at the dry end of the tunnel. An effort can be made to improve this condition by adjusting the manually operated globe valve to admit more fuel, so that the low-fire temperature level within the tunnel is raised. The flow in the modulating valve branch can be restricted, so that variations in flame intensity will be minimized. However, constant vigilance will still be necessary to prevent excessive tunnel temperatures during tunnel charging and under other varying load conditions.

When a modulating controller is placed on this system, the opening of the modulating valve will be related to the heat demand. Thus a comparatively even tunnel temperature will be realized. Obviously, the globe valve can be used to desensitize the action of the controller. However, care should be taken in its adjustment for low-fire conditions so that the resulting temperature is not in excess of that desired in the dehydrator under minimum-load conditions—that is, when part of the tunnel is shut down for the changing of cars.

As a second example, let us suppose that the same dehydrator employs a confined flame unit and a combustion tube similar to that shown in figure 53 of the preceding section. The same close regulation of temperature is required. Let us analyze this example and assume that an off-on controller is used. The manually operated globe valve shown in figure 55 is adjusted so that the low-fire temperature level is approximately 10° F. below the set temperature of the controller. A small drop in temperature below the set temperature will open the motorized valve completely, and the burner will be under high-fire conditions. The immediate reaction will be to store up heat energy in the refractory lining of the combustion tube. There will be a small time lag before full flame intensity is manifested by a maximum increase in heating effect on the drying air. Thus the large heat inertia of the heating tube has a dampening effect on the fluctuations of temperature produced by the off-on controller. Variations in temperature regulation will, in all probability, be within acceptable limits. Further dampening of the maximum amplitude produced by the off-on controller can be obtained by a fixed throttling device placed in series with the motor-operated valve.

As a third example, let us assume that the same counterflow finishing dehydrator used with onions is steam-heated. Close temperature regulation is again essential. The problem is, again, to select a suitable type of controller. Admission of large quantities of steam to the heating coil will produce a delayed heating action and the tunnel temperature may exceed the set temperature. If the steam-supply piping and controls were similar to those shown in figure 56, the manually operated valve might again be used to throttle the steam in order to maintain a temperature level within close but safe approach to the set temperature. If we assume that 125° F. is the safe temperature level for a set temperature of 135° under this condition of operation, the sensitivity of the modulating controller must be adjusted so that at a given temperature, for example 120°, the motorized valve would be fully opened. At 135° the valve would be fully closed. It will be seen, then, that at some point between 125° and the set temperature, the system would come to equilibrium, even though this temperature is obviously lower than the set temperature. The operator must recognize this fact, and readjust the controller indicating point and recording arm so that they indicate and record the new equilibrium temperature; otherwise his records and the true tunnel temperatures will be at variance. If the modulating controller is of the simple type, this action must be carried out as often as the load in the tunnel changes. Instruments are available, however, which perform this function automatically. When this feature is included on a modulating controller, it is said to have re-set features.

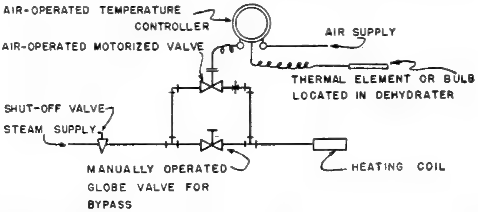

FIGURE 56.—Typical simplified steam heater control diagram.

Other special features are obtainable on temperature-control instruments. One type deserving special mention is the cam-operated time-temperature controller. This unit includes a clock-driven cam that moves the control arm in accordance with some prearranged temperature schedule. The controller can be of either the off-on or modulating type. This type is especially suited for use on a cabinet dehydrator in reproducing scheduled temperature variations.

In addition to the control of dry-bulb temperature, specially adapted sensitive elements fitted with wicks or other wetting devices can be used for indicating, controlling, and recording wet-bulb temperatures. An important matter is the care of wicks and wet-bulb devices. Care should be taken to keep these surfaces clean. It is preferable that the water used in the appliance be distilled, since water containing calcium and other salts will leave a residue after the water has evaporated. These salts contaminate the wick and cause the instrument to give a false reading. If hydrant water is used in wetting the bulb, frequent attention should be given to cleaning or renewing the wick. Multiple-pen units can be obtained for such purposes as indicating, controlling, and recording dry-bulb temperatures and wet-bulb temperatures simultaneously. Many motor-operated devices, besides valves, are available for use with temperature controllers. These can be used for the operation of dampers and other devices necessary in the automatic operation of a dehydration unit.

MECHANICAL MOVEMENT OF AIR IN DEHYDRATORS

Fans generally used for the mass movement of air in dehydrators can be divided into two classes: (1) Propeller, axial-flow, or disk fans, and (2) centrifugal or rotary impeller fans. Disk fans are generally limited to delivery of air against relatively low static pressures, although some special designs are capable of developing a pressure of 10 inches of water or higher. Centrifugal fans, on the other hand, can be used against either high or low static pressure. Installations in which low-static-pressure disk fans are suitable include cabinet driers, low-performance tunnel driers, and belt-conveyor driers. Centrifugal fans can be employed in addition, on high-performance tunnel driers, bin driers, and in general on installations where the static pressures are substantially higher. A centrifugal fan consists essentially of an impeller or fan wheel and a casing or housing. The design of these parts can be varied to suit peculiarities of the load. The casing has either of two functions or both; one is to transform velocity pressure into static pressure and the other is to collect and conduct the air to the point of discharge, or fan outlet.

Centrifugal or Rotary Impeller Fans

Centrifugal impellers can be roughly divided into three classes: (1) Those with forward-curved blades, (2) those with straight radial blades, and (3) those with backward-curved blades, sloping away from the direction of rotation. Impellers thus formed are termed slow-speed, moderate-speed, and high-speed types, respectively. Their ranges may be overlapping; therefore, each of these types may be used for the same work. Fan characteristics in each group may, however, be varied by changing the depths of the blades. Thus, fans with deep blades will develop relatively high static pressures, whereas fans having short or shallow blades will handle large volumes at low pressures. This latter type is sometimes designated as a volume fan.

Although the forward-curved-blade centrifugal fan is widely used on tunnels originally designed as fruit dehydrators, they are not best suited for that purpose. The probable reason for their original adoption lies in the fact that the relatively low shaft speed required for a given discharge was applicable to use with steam or gasoline engines.

The forward-curved fan has many characteristics that are unsuited to dehydrator service. First, the fan power increases when the static pressure of the fan is reduced and therefore the fan absorbs maximum power at free discharge. However, at the normal operating static pressure, which is usually a condition near the point of maximum mechanical efficiency, the fan power may be less than one-half of free discharge power. Second, the fan has an unstable capacity or volume characteristic when operating at static pressures approaching the shut-off condition. Third, the slow speed of rotation necessitates an appreciable speed reduction if a standard electric motor is used to drive the fan.

Systems having variable static pressure loading as found in tunnel dehydrators and bin driers are best served with fans having backward-curved blades. This type of fan, which is sometimes known as a limit-load or nonoverloading fan, has operational characteristics which, at any given speed and specific volume, prevent it from absorbing more than a limited amount of power. This is of special importance when the fan is used in dehydrating systems where the static pressure in the tunnel drier may be suddenly decreased as a result of opening of doors, or, in the case of a bin drier, where the static load can be changed by removal of the product from the bin.

Propeller, Axial-Flow, or Disk Fans

Unless very special designs are used, the disk-type propeller fan is generally suitable for use only where the static pressure is less than 1 inch of water pressure. There are two general classes of disk-type propellers: Those with thin, steel, curved blades, and those with air-foil sections similar to those used on airplane propellers. The former type is available commercially and the latter can be readily built of wood. Irrespective of the type used, the entrance and exit cones should be streamlined and the propeller shrouds should be built with minimum clearances in order to secure the highest efficiencies.

High-speed disk fans are likely to be very noisy, and this factor may restrict their use. When properly applied, they are efficient and constitute a relatively cheap means of obtaining a high volume of air movement with a minimum of equipment.

Although simple in appearance and operation, propellers are intricate in design. An improperly designed propeller may be extremely inefficient, wasteful, and sometimes very dangerous. Properly designed, however, they can be readily constructed and are efficient and safe. Those who contemplate their use should make use of publications that contain adequate design information (*5*, *8*, *17*, *23*, *25*).

Application of Fan Laws in Choice of Fan

The proper choice of fan size and the prediction of its performance under specific conditions requires a knowledge of basic fan laws. These laws are applicable to all geometrically similar centrifugal or disk-type fans. It should be understood that two fans are geometrically similar only if they are alike in all proportions and in all details regardless of size.

B = barometric pressure.
D = diameter of fan wheel.
hp. = fan power, horsepower.
Q = capacity or volume of air per unit of time, cubic feet per minute (c. f. m.).
Ps = static pressure of fan, inches of water.
r. p. m. = fan speed, revolutions per minute.
T = absolute temperature of air (°F. + 460) or (°C. + 273).
V = specific volume of air, cubic feet per pound (specific volume of air at standard conditions for fan tables is approximately 13.3 cubic feet per pound of air).

1. For a given fan speed and a constant specific volume of air when the size of fan varies:

a. $Q \propto D^3$
b. $Ps \propto D^2$
c. $hp \propto D^5$

2. For a given fan size and a constant specific volume of air when the speed of the fan varies:

a. $Q \propto (\text{r. p. m.})$
b. $Ps \propto (\text{r. p. m.})^2$
c. $hp \propto (\text{r. p. m.})^3$

3. For a given fan size and a constant static pressure when the specific volume of the air varies:

$$(\text{r. p. m.}, Q, \text{hp.}) \propto \left(\sqrt{V}, \frac{1}{\sqrt{B}}, \sqrt{T}\right)$$

4. For a given fan size, capacity and speed when the specific volume of air varies:

$$(\text{hp.}, Ps) \propto \left(\frac{1}{V}, B, \frac{1}{T}\right)$$

5. For a given fan size and a constant amount of air by weight when the specific volume of air varies:

a. $(Q, \text{r. p. m.}, Ps) \propto \left(V, \frac{1}{B}, T\right)$

b. $(\text{hp.}) \propto \left(V^2, \frac{1}{B^2}, T^2\right)$

In order to apply these fan laws it is necessary to understand the nature of the static pressure load of the fan as governed by the resistance of a given dehydrator system. It is therefore well to add the following laws:

6. For a constant specific volume of air, the static pressure of a given dehydrator system varies directly as the square of the air velocity.

$P_s \propto U^2$, when V=constant.

Ps=static pressure of the dehydrator system and fan, inches of water.

U=the air velocity either in the dehydrator or at the fan outlet, feet per minute.

V=specific volume of air, cubic feet per pound.

7. For a given dehydrator system and a constant amount of air by weight when the specific volume of air varies, the static pressure of the system changes directly as the specific volume.

$P_s \propto V$, when W=constant.

W=total weight of air per unit of time, pounds per minute.

A comparison of laws 6 and 7 with the fan laws shows that Nos. 2 and 5 may be directly applied to any given dehydrator system. Their use is best demonstrated by specific examples as follows:

Example 1.—Assume that a fruit-drying tunnel is to be converted into a vegetable dehydrator. The measured air velocity in the drying section is 400 feet per minute. The observed fan speed and power are 700 r. p. m. and 10 hp., respectively. If the same fan is used and the specific volume of air remains unchanged, what fan speed is needed to furnish an air velocity of 600 feet perminute in the drying section? How much power will the fan absorb at the new operating condition?

Applying law 6 the static pressure of the dehydrator system and fan both vary with the square of the air velocity. Therefore (from 6 and 2b) the static pressure at this new condition will be $(600/400)^2$=2.25 times the original static pressure. The new fan speed must be 700× (600/400) =1,050 r. p. m. since (from 2a) the capacity is directly proportional to fan speed. Likewise, the fan power for this condition (from 2c) is $10 \times (500/400)^3$=33.75 hp.

Example 2.—Suppose 4,000 pounds of air per minute is necessary for the removal of moisture from a given dehydrator; the specific volume of air at the fan is 16.7 cubic feet per pound and the static pressure of the dehydrator system using standard air conditions is 1.45 inches of water. If standard fan tables are used, what size fan shall be chosen for this dehydrator? What is the correct fan speed and how much power will the fan absorb? Assume there is no air leakage.

The specific volume of standard air is approximately 13.3 cubic feet per pound of air. Therefore the rated capacity of the fan will be 4,000 × 13.3, or 53,200 c. f. m. The corresponding rated static pressure will be 1.45 inches of water. Using the standard fan tables, assume it is found that a fan of suitable dimensions operates at a speed of 475 r. p. m. to deliver the rated volume of air against the specified static pressure and the table lists fan power as 19 hp.

Applying law 5a, both capacity and fan speed are directly proportional to the specific volume of air. Hence the proper fan speed is $475 \times \frac{16.7}{13.3} = 596$ r. p. m. The power absorbed by this fan (5b) will vary directly as the square of the specific volume, $19 \times (16.7^2/13.3) = 29.8$ hp.

It is now possible to predict the actual operating capacity and static pressure of the fan by applying law 5a, which shows that both vary directly as the specific volume. Therefore, the actual capacity is $53{,}200 \times \frac{16.7}{13.3} = 66{,}500$ c. f. m. and the actual static pressure of the fan is $1.45 \times \frac{16.7}{13.3} = 1.81$ inches of water.

BIN-TYPE FINISHING DRIERS

The bin finisher provides an efficient, relatively inexpensive means of finally drying vegetables to low moisture content. It is compact and has a comparatively high heat use. If it is used as final drier, better use can be made of the preceding dehydrator, whether it is a tunnel, cabinet, or belt type. All of these types use large areas of loading space for the reduced volume of thinly spread, partially dried product.

If a bin drier is added to a system and, further, if additional heat-generating capacity is available in the preceding drier, then the plant capacity is potentially increased. The shortened retention time required by the preceding driers in reducing the moisture of the product only to a condition satisfactory for bin drying (approximately 10 to 15 percent moisture) permits the system to handle additional tonnage. This additional tonnage of course requires additional heat.

Very little is known of the performance characteristics of bin driers. Their use as an expedient for increasing plant output or for carrying the dryness of the product to low moisture limits is, however, of unquestionable value. As a secondary aid, the bin driers can be used to supplement the plant's finished-product storage facilities. Being relatively simple and easy to build and operate, finishing driers are becoming standard equipment in most dehydrating plants.

Types of Bin Driers

There are two basic types of bin driers—the batch-process bin drier and the continuous bin drier. The continuous bin drier usually consists of a single unit, whereas the batch-process drier is almost invariably a multibin drier.

The continuous bin finisher, because of its operating characteristics and its size limitations, is generally confined to use in small plants. The unit consists of a large storage bin designed for working depths ranging approximately from 3 to 8 feet. Drying air is introduced through louvers at or near the bottom of the bin. The bin must be of airtight construction except for an exhaust port located in the top or at some other position above the active bin level. A gate is provided in the bottom of the bin to permit gravitational removal of the product in progressive layers. To facilitate removal and to prevent arching, mechanical or electrical agitating or shaking devices are sometimes provided. Figure 57 shows a typical design for a continuous bin finisher intended for use with onions. Note the location of the agitator.

When the bin is in operation, the partially dried material is allowed to enter in a steady stream, at such a rate that it keeps the bin completely filled. A draft of heated dry air is forced through the louver inlets at the bottom and the product dries progressively upward; therefore, the dried product at the bottom is removed at the same rate as the bin is loaded from the top.

The batch-process bin finisher is somewhat similar in design. A gate is located at the bottom to permit dumping of the entire bin. Three or more bins are usually required, as will be explained later. In operation, the entire bin is filled with the partially dried product; the material dries progressively upward, and, as soon as the material near the top is dried to the required moisture content, the entire bin is dumped and a new cycle is commenced.

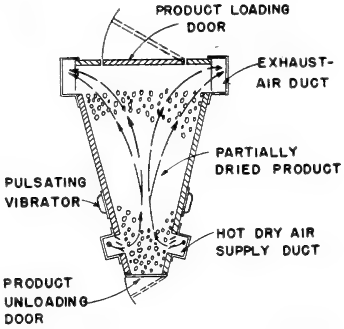

FIGURE 57.—Continuous-bin finisher.

Operation of Bin Driers

During normal operation, the product, as loaded into the bin drier, contains not over 15 percent moisture. This partially dried product is of sufficient stiffness so that it will not crush, and will form a solid mat. Therefore care should be taken not to tamp the product during loading operations. The charging depth may range between 2 and 6 feet. Under this condition of loading, air can be readily forced through the material by standard-design blowers.

As a product loses its moisture, its rate of drying becomes slower and slower. The latent heat necessary for evaporation will be required at a proportionally slower rate. Since the air is the source of heat supply and transfer medium, the required quantity and velocity of air become correspondingly smaller. The air bathes the product and carries away the diffused moisture as it is released. The principles involved are discussed in publications by Furnas (*15*) and Gamson, Thodos, and Hougen (*16*).

The depth of bed will determine to a large degree the batch retention time. Usually bins are operated at the upper limit of the usable temperature range. If excessive bed depths are used, the dried product on the bottom may be injured by prolonged exposure to maximum temperature. Therefore, to reduce the batch-retention time, relatively high velocities should be used.

An undesirable condition that may arise is illustrated by the following example: Let us assume that a deep-bed bin drier is being used to finish potatoes. Assume further that the potatoes have been scraped from drying trays of the preceding stage in a room having a temperature of 60° F. It is probable, then, that when the bin is filled with these potatoes, the average bin temperature will be in the neighborhood of 60°. Assume that air at a relatively low velocity and temperature is circulated through this bed. The air will pick up moisture and gradually drop in temperature until, at a certain point in the bed it can no longer dry the product. From this point, the cool product will gradually reduce the air dry-bulb temperature until, at a point within the bed, the air becomes saturated. Further penetration of the air, while in contact with the cold bed, will reduce the air temperature below the dew point; thus moisture will be condensed upon the product. If this condition arises, the wetted product may be injured. The condition can be remedied by increasing either the temperature or the velocity or both, by decreasing the bed depth, or by providing auxiliary internal bin heating devices.

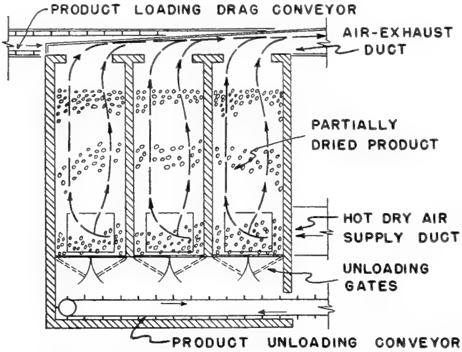

FIGURE 58.—Multibin finishing drier.

An operator can detect faulty bin operation by taking samples from the uppermost surface of the product periodically throughout the drying cycle and analyzing them for moisture content. The time intervals should be fairly close because the region of condensation, which is likely to be fairly shallow in depth, might otherwise not be detected.

Regardless of the velocity and temperature of air employed, a bin drier will ultimately carry the product through the full depth of the bed to a condition approximating equilibrium with the entering air. This, of course, is based on the assumption that heat loss due to radiation, convection, and conduction from the outer surfaces of the bin are relatively small.

Batch drying is intermittent in operation; therefore several bins are usually provided to permit continuous drying operations. At least three bins are usually employed, and while one is being loaded the others may be used in drying or unloading. Figure 58 shows a suitable multibin finisher design. Any number of units in addition to the three shown can be provided to suit plant capacity.

Determining Needed Capacity

To illustrate a method of determining required capacity, we may consider a small onion-drying plant producing approximately 225 pounds of flaked onion per hour. Laboratory tests indicate that a 5-foot depth of product can be dried from 12 to 4 percent moisture in approximately 8 hours. The plant will accommodate a bin not over 10 feet wide. What should be the bin proportions?

The bulk density of nearly dried flaked onions is found to be approximately 15 pounds per cubic foot. Since one continuous bin is to be installed, it must have sufficient volume to accommodate the entire output of the plant for an 8-hour period. Its capacity can be computed by multiplying the retention time in hours by the plant output per hour and dividing by the bulk density of the product. Thus the volume of the bin equals 8×225/15 or 136 cubic feet. With a bed depth of 5 feet, the cross section of the bin must be slightly over 27 square feet. Since the bin is to fit into a 10-foot-wide space, a bin 4×7×5 feet deep may be satisfactory.

Let us suppose that a unit of this size has been built, and that subsequent tests show that the 8-hour drying time is too short. If the highest permissible air temperature for drying onions is already in use, the bin capacity can be further increased by resorting to higher air velocities. If, however, the fan is operating at full capacity, the only remaining alterable condition is to reduce the moisture of the entering product by increasing the retention time in the preceding stages.

Increased drying in the preceding stage affects the bin capacity in either of two ways. First, the longer retention period in the preceding stage decreases the input to the bin drier. Second, the reduction in total moisture to be removed by the bin drier shortens retention time here. Hence, under a particular ratio of primary to secondary retention time, a balance will be reached. Although predictable with a fair degree of accuracy, the optimum ratio can best be found by trial and error.

The balance established under one set of drying conditions will not necessarily hold for all other drying conditions. For example, the operating balance established with daytime initial drying and nighttime bin drying may not be suitable if the drying cycle is reversed. This change in retention ratio from day to day is obviously undesirable. However, a safe working ratio can be established, based on the most unfavorable conditions, and thus a workable solution can be obtained. The effect is to produce extra drying some of the time. However, the ease of operation on a fixed schedule will in all probability offset the expense of the additional heat. The loss of product weight due to extra drying will be negligible.

As an example of multibin driers, let us assume that the management of a medium-sized plant is considering the installation of a multibin finisher to increase the plant capacity. The plant is to be able to process 300 pounds of nearly dry potatoes per hour, having a moisture content of 12 percent. Packaging is to be done only during one 8-hour shift. How large a multibin finisher will this plant require?

The bulk density of partially dried potatoes is found to be 15 pounds per cubic foot. Material will then be delivered to the bins at a rate of 300/15 or 20 cubic feet per hour, or 160 cubic feet per shift. Assume that previous experience indicates that 12 hours are required to reduce the moisture content of potatoes from 12 to 4½ percent. The bins, therefore, must have a minimum total volume of 12×20 or 240 cubic feet if packaging operations are to be continuous. The bins selected for use are to have a working volume of 80 cubic feet. The minimum number of bins required would then be 240/80 or three bins. However, since the product is to be packaged only during the 8-hour-day shift, three bins are inadequate.

For purposes of computation, let us consider the period immediately after the 8 hours of packaging. At this time, at least three bins are filled or partially filled because of the 12 hours required in the bin drier. In addition to these three bins, four more are required to dry and store the product that will be produced during the coming 16 hours when no packaging is done. One additional bin must also be provided for use during the time the first bin is being emptied the following morning. Therefore it is obvious that at least eight bins are required for this operation.

Little is known about drying rates of various vegetables in bin driers, but, as a basis for determining the approximate number of bins required, it is safe to assume that the retention time will be from 6 to 9 hours for an air velocity equivalent to 80 or 100 cubic feet of air per minute for each cross sectional square foot of active bin capacity. The maximum incoming air temperature should not exceed 10° F. below that recommended for the dry-end temperature in a counterflow dehydrator for the same vegetable. It may be necessary with vegetables that are very sensitive to heat, to keep the temperature even lower than this.

If final results indicate that the capacity of the finishing unit is below the capacity expected, the operator need only increase the retention time in the preceding drying stages until a working balance is reached. This condition was illustrated by the previous example.

Air Desiccators

Bin drier operation will vary considerably between humid and arid regions. If high relative humidities are prevalent in the plant locality, it will be almost essential to employ some means of drying the air before it is introduced into the bin finisher. A unit for this purpose is called an air desiccator or air dehydrator. The former is the preferable designation, because the other may lead to confusion.

One of the most satisfactory means of drying air is through the use of a chemical adsorption or absorption drier. Units of this type are capable of delivering air at fairly high temperature and low absolute humidity. This method obviates the necessity of reheating the dehumidified air, as would be required by a dehumidifying unit using refrigeration. This factor may be of considerable importance in the selection of an air-desiccating method.

When an air desiccator is used with a bin finisher, it may become desirable to recirculate all or part of the drying air. In multibin operation, the air expelled from each bin will have a different absolute humidity, because the products in the bins are at various stages of dryness. In practice, however, the air from each bin is discharged into a common return duct. If the absolute humidity of the mixed air in the return duct is less than that of the outside air, then it should be recirculated; if not, it should be entirely wasted to atmosphere. On "borderline" installations this condition may vary from day to day; hence repeated daily checks should be made.

Sources of Heat

The air supply to bin driers is preferably heated by steam. Direct-fired units are not recommended, because the product may acquire a disagreeable taste from the flue gases. There is also a fire hazard with the open flame, which may cause dust explosions. The amount of heat required by a bin drier is relatively small; hence, the heat wasted by not recirculating it is negligible. The problem of recirculation should be decided on the basis of absolute humidity only.

OTHER TYPES OF DEHYDRATORS AND THEIR USES

Patent files and other publications describe numerous designs of food dehydrators. The truck-and-tray tunnels, the truck-and-tray cabinet, and the belt conveyor are described in previous pages of this manual and their operation has been discussed in detail because of their extensive use in the dehydration of vegetables and fruits (fig. 59). Other types of dehydrators and their uses are described below.

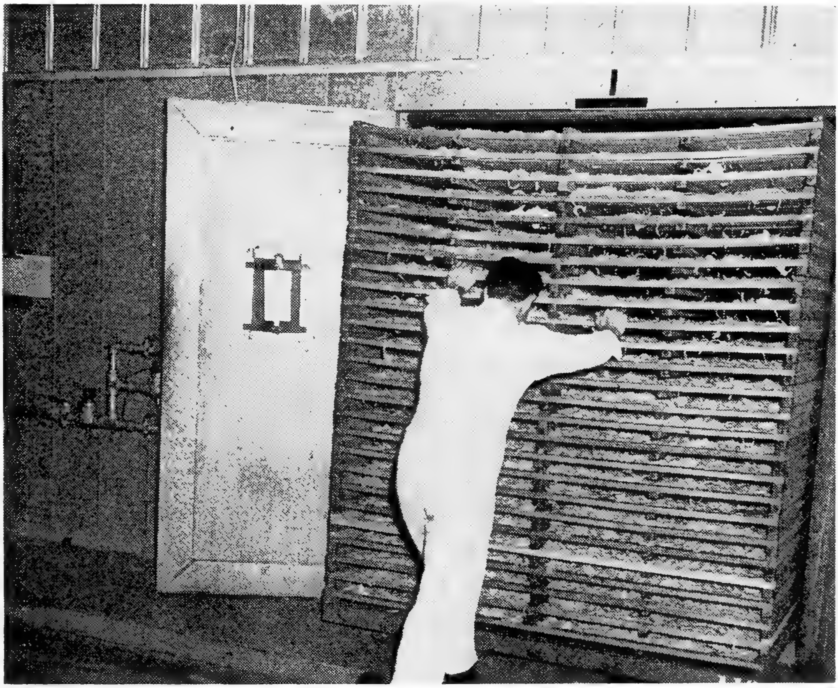

FIGURE 59.—Truck carrying trays of sliced onions enters a tunnel dehydrator.

Spray Driers

Spray drying is based upon the general principle that moisture is removed rapidly from a finely divided substance suspended in an atmosphere capable of absorbing the water vapor and of supplying the heat necessary for its evaporation. Under these conditions it may be assumed that rapid evaporation maintains the particle temperature at or near that shown by a wet-bulb thermometer until drying is substantially complete, after which the powdered product is removed from the heated zone so quickly that thermally induced damage is avoided even when high dry-bulb temperatures are employed.

The necessary situation is attained in practice through the use of a large drying chamber, usually cylindrical in form with a cone bottom, but sometimes in the shape of a box. The cylindrical form ranges in commercial practice up to about 20 feet in greatest diameter and 40 feet in over-all height. Collectors that accumulate the powder are attached to, or built into, the drying chambers. Fans, heaters, and baffles induce a rapid whirling flow of hot air or flue gas through the drying chamber, collector, and exhaust duct. The product to be dehydrated is introduced into the hot-air stream near its inlet in the form of a fine mist produced by a spray nozzle. Moisture is removed in the space of a few seconds and the resulting fine powder is deposited in the dust-collection system, from which it is removed, cooled, and packaged, usually in a continuous operation.

The spray drying process is particularly adapted to the production of dried milk and eggs. Certain vegetable purees are readily dehydrated for use in soups, baby foods, and similar products. Tomatoes and most of the fruits have not thus far been successfully spray-dried on a commercial scale, presumably because of their high content of low-melting, hygroscopic sugars which impart to the dried product a tendency to stick to the equipment rather than to flow smoothly through it.

Vacuum Driers

Water can be evaporated from moist substances at relatively low temperatures in a vacuum, and substances that are extremely sensitive to heat, such as serums, are accordingly dried under these conditions. If the vacuum is sufficiently high the temperature may be lower than the freezing point. The process has the additional advantage that there is little or no contact with oxygen during the drying. Equipment for vacuum processing must be of heavy construction to withstand the pressure of the atmosphere, and all closures must be fitted with extreme precision to avoid leaks. For this reason equipment is expensive.

Most types of dehydration equipment can be built to operate under vacuum. Rotary-drum driers and rotary-kiln driers have been so used for some time. A type of cabinet dehydrator adapted for vacuum operation is perhaps used more extensively for food products than others. It consists of a cast-iron shell in which shelves internally heated by steam, hot water, hot oil, or electricity are placed. Trays loaded with material to be dehydrated are placed on the shelves. Heat transfer is slow and inefficient in the absence of a vehicle such as moving air, and time for complete dehydration is therefore relatively long. A recent development in this field employs a specially designed fan to circulate the attenuated water vapor present in the dehydrator over a heater and then over the charge. In this way evaporation is greatly accelerated and the equipment, though operating batchwise, may prove to have a substantial capacity in terms of dried product. Another recent development is a continuous tunnel operating under vacuum. Neither of these devices has as yet been extensively used in commercial dehydration.

The principal handicap to practical use of vacuum driers for dehydrating fruits and vegetables, namely, the difficulty of transmitting heat to the product rapidly enough to evaporate a large quantity of water effectively, can be largely overcome if the drier is used only for the finishing step in a multistage dehydration process. Preliminary steps may remove 95 percent or more of the moisture originally present in the material; from that point on the vacuum drier is able to operate very effectively. A combination process of this nature is being used commercially for the final dehydration of certain fruits, which are first dried in hot air to the usual moisture content for dried fruits—about 20 to 25 percent.

Dehydration of fruits or vegetables to final moisture contents of only 1 to 2 percent can be accomplished in one of two ways—by the use of highly desiccated air as the drying medium or by the use of a vacuum drier. Choice between these two methods may be determined by availability of the equipment or by the sensitivity of the nearly dry product to oxidation by warm air.

Rotary-Drum Driers

Drum drying provides means for rapid dehydration of solutions, slurries, purees, and the like, spread in a thin layer on a heated surface from which the dried product is removed continuously. The equipment consists of an internally heated revolving drum, upon the outer surface of which the substance being processed is spread at one point while the dried product is removed by means of a blade at another. The temperature and rate of revolution of the drum are so chosen that drying is completed in the time required for the material to travel from the point of spreading to the blade that removes the product.

The operation can be carried out in air or in a vacuum. In the latter case heat-sensitive products are better protected since lower operating temperatures can be maintained. The material being dehydrated can be spread on the surface of the drum by spraying it, by a "doctor" blade, or by use of two drums placed parallel with a small clearance between. In the latter case both drums can be used as driers, in which event they will be similar in size, or one may be small and used only for the purpose of providing a small clearance through which even spreading on the large drum can be attained.

Many products are removed from the drum in the form of continuous sheets which are conveyed to a mill operating in a suitably conditioned atmosphere where the dry product is reduced to a powder and then packaged.

The drum-drying process is widely used for the production of dried milk and to a lesser extent for certain fruit and vegetable purees. The form of the product is confined to thin flakes and powders.

Rotary Driers

Rotary driers are rotating drums inclined at a slight angle from the horizontal. The wet substance is fed in at the high end and is conveyed with constant tumbling toward the low end, from which the dried product is continuously removed. Drying is facilitated by a current of air, either counterflow or parallel flow, induced by suitably situated fans, and heat may be simultaneously supplied on the outside of the drier. Construction is of either the single- or double-shell type. The latter affords greater protection of the product from damage by burning. Double-shell driers are sometimes provided with louvers in the inner shell through which air is admitted in direct contact with the material.

Rotary driers are efficient and extremely useful in drying many substances, but they have found little application in the field of fruit and vegetable dehydration. The constant rolling or tumbling of the wet product destroys the characteristic form of the pieces (slices, strips, or cubes) and may result in production of a large proportion of powder. Rotary driers have been used successfully for the drying of precooked ground meat.

Apple and Prune Kiln Driers

A distinctive type of kiln drier finds extensive use in dehydration of apples and prunes in the Pacific Northwest. The drier consists of a two-story building in which the lower story houses the central heating system, from which heated air is circulated through wooden ducts to the kilns above. The kiln proper consists of a series of stacked, shallow, wooden bins having slotted floors on which the prepared fruit is placed in layers from 6 inches to 24 inches in depth. Warmed air from the heaters below passes upward through the fruit and is removed through a duct at the apex of the V-shaped roof. In some modern kilns the air circulation is speeded up by an induced-draft fan at the roof, and in some cases provision is made for recirculation of part of the exhaust air. When apples are being dried, it is common practice to turn the material with shovels or forks after 4 to 6 hours of drying.

Initial temperatures of 150° to 165° F. are usual. Final drying should be carried on below 160° F. Driers of this type are built in capacities ranging from a few tons to 120 tons of raw material per day. Their initial cost is relatively low but difficulty of control is not conducive to the highest quality of product and drying costs are likely to be high as a result of large heat losses. Kilns are not well adapted to the drying of cut vegetables because vegetables do not stand the necessary rehandling so well as fruits, and because the relatively low air velocity makes rapid drying impossible.

MULTISTAGE DEHYDRATION

It should be apparent that each of the types of dehydrators described in foregoing pages has its peculiar advantages and disadvantages. No one of them is "best" under all conditions. No one of them is necessarily the best for all of the stages of dehydration of a single lot of moist fruit or vegetable. The advantages of a combination of parallel-flow and counterflow tunnels over either of them separately have been pointed out. Such a combination is one example of a multistage dehydration process.

While a complete discussion of the factors that determine the advisability of combining different kinds of dehydrators belongs in the realm of dehydrator design, rather than operation, the following summary may assist the operator of such a system to understand what can be done with it.

Changes in Material as Drying Progresses

The fundamental factor at the base of all combination systems is the enormous change in properties of the material as it dries. A freshly blanched piece of vegetable is soft and easily crushed, is indeed a mass of water held together by a tenuous cell structure; its vapor pressure is nearly equal to that of pure water. In contrast, the same piece of vegetable after drying to 5 percent moisture is greatly shrunken in volume and distorted in shape, is hard and may be very brittle, and its vapor pressure may not be more than 10 or 15 percent of the vapor pressure of water. These properties all change as the drying progresses, but not all at the same rate.

Hence the conditions which would be "ideal" for drying change as the piece dries. When the piece is very wet the water will evaporate very rapidly if a great deal of air is supplied, and that air may be very hot without burning the piece. At the same time the piece will be too tender to stand more than a minimum amount of handling. Essentially similar conditions prevail while at least the first half to three-quarters of the weight is being lost through evaporation. As the moisture is still further reduced the piece (which will have already undergone most of the shrinkage in volume that it will experience) becomes tough or leathery. The rate of evaporation may not be more than a half or a third of what it was at first, even though drying conditions are kept the same; increasing the air velocity past the piece has no perceptible effect on the rate; the temperature of the piece rises almost to the dry-bulb temperature of the air. "Ideal" conditions now demand a lower temperature than at first, and the use of a high air velocity would be a needless waste of power. However, the piece will now withstand handling, tumbling, or deep piling without damage. Conditions substantially similar to these prevail down to a moisture content of about 10 to 15 percent. Below that point, and more and more clearly as the moisture content falls further, conditions change again. The piece becomes hard and brittle. The rate of further evaporation is determined almost entirely by the thickness of the piece and the dryness of the air.[12] The rate will perhaps become less than 1 percent of what it was at the beginning of the drying. "Ideal" conditions now call for a slow current of dry air, not too warm, and very little mechanical disturbance of the product.

The usefulness of different kinds of dehydrators at different stages of drying will depend not only on these physical factors but also on economic ones. It is an economic waste to use a large and expensive piece of equipment to perform work that a small, cheap one will do as well. Consideration of the labor or complications involved in rehandling the product may favor one kind of transition over others.

Examples of Multistage Systems

Out of the very great number of possible combinations, the following may be mentioned. Not all of these are now in commercial use.

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[12] More exactly, by difference between the vapor pressure of the piece and the partial pressure of moisture in the air.

1. Three-stage conveyor-belt drier, followed by a drying bin. The bin itself may be continuous in operation, in which case it is essentially a fourth stage of the conveyor, arranged for very deep piling.
2. Three-stage conveyor-belt drier, followed by a continuous vacuum-finishing drier.
3. Counterflow tunnel, followed by a finishing bin. This combination has been used in commercial operations for some years.
4. Cabinet drier, followed by a finishing bin. Use of the bin releases the cabinet from the part of the run on which it is normally most inefficient.
5. Rotary drier, followed by vacuum drier. The rotary may be used for most of the drying of some products which are tough enough to stand the tumbling action, but it tends to reduce a nearly dry product to powder.
6. Parallel-flow predrying tunnel, counterflow secondary tunnel, and finishing bin. A combination which is being widely adopted for large commercial operations.
7. Parallel-flow predrying tunnel, followed by two-stage conveyor-belt drier. The tunnel takes the part of the cycle for which the conveyor drier is least well adapted. The second stage of the conveyor drier can be designed for deep piling, as in a finishing bin.
8. Center-exhaust tunnel followed by finishing bin. The combination is equivalent to that of No. 6 above, except in the manner of handling the product between the first and second stages (fig. 60).

FINISHING AND PACKAGING

The equipment required in finishing and packaging dehydrated products ordinarily includes the following: A bin drier (if used), a picking belt, one or more shaking or jogging stands (if used), placed at the end of the picking belt, gassing equipment in plants that dehydrate carrots and cabbage, scales, a can seamer or bag and carton closer, space for boxing and labeling, a clean dry space for the storage of cased dehydrated products and for empty cans, bags, and cartons, and finally a loading platform. The floor area required for finishing and packaging in a plant that handles carrots at the rate of 30 tons daily has been estimated as shown below.

	Area in square feet
Bin drier	120
Picking belt 6 x 2½ feet (2 women)	125
Can shaker	10
Gassing unit (vacuum chamber and pump)	50
Scales	10
Can-lid closing machine or carton and bag-sealing unit	15–75
Space for boxing, labeling, and stenciling	50
Storage of empty 5-gallon cans and boxes, 1½ carloads	750
Storage of filled 5-gallon cans, boxed, 1½ carloads	750
Aisles	640
Car shipping platform	400
Total	3,000

The floor space required for this department in a 25-ton plant is estimated to range between 2,400 and 4,100 square feet. (See p. 10.) This estimate is based on diced carrots, packed as follows: 14 pounds in 5-gallon cans, 2 cans per case, 1.75 cubic feet of gross volume per case having outside dimensions of 20½ x 9¾ x 14¾ inches. A boxcar with a volume of 3,150 cubic feet will hold approximately 1,800 cases of 2 cans each and a net weight of 50,000 pounds of dehydrated carrots. It is good practice to store these cans prior to shipment, 8 high on their sides, which will require an area of 490 square feet per carload exclusive of aisles.

The space used for finishing and packaging should be between the dehydrator and the loading platform, and should be a separate room, partitioned off from the rest of the plant where the humidity will be higher. The doors and windows should be screened to keep out flies. It is desirable to have the bin drier in this room, but the air discharge must be vented to the outside. Air in the room must be

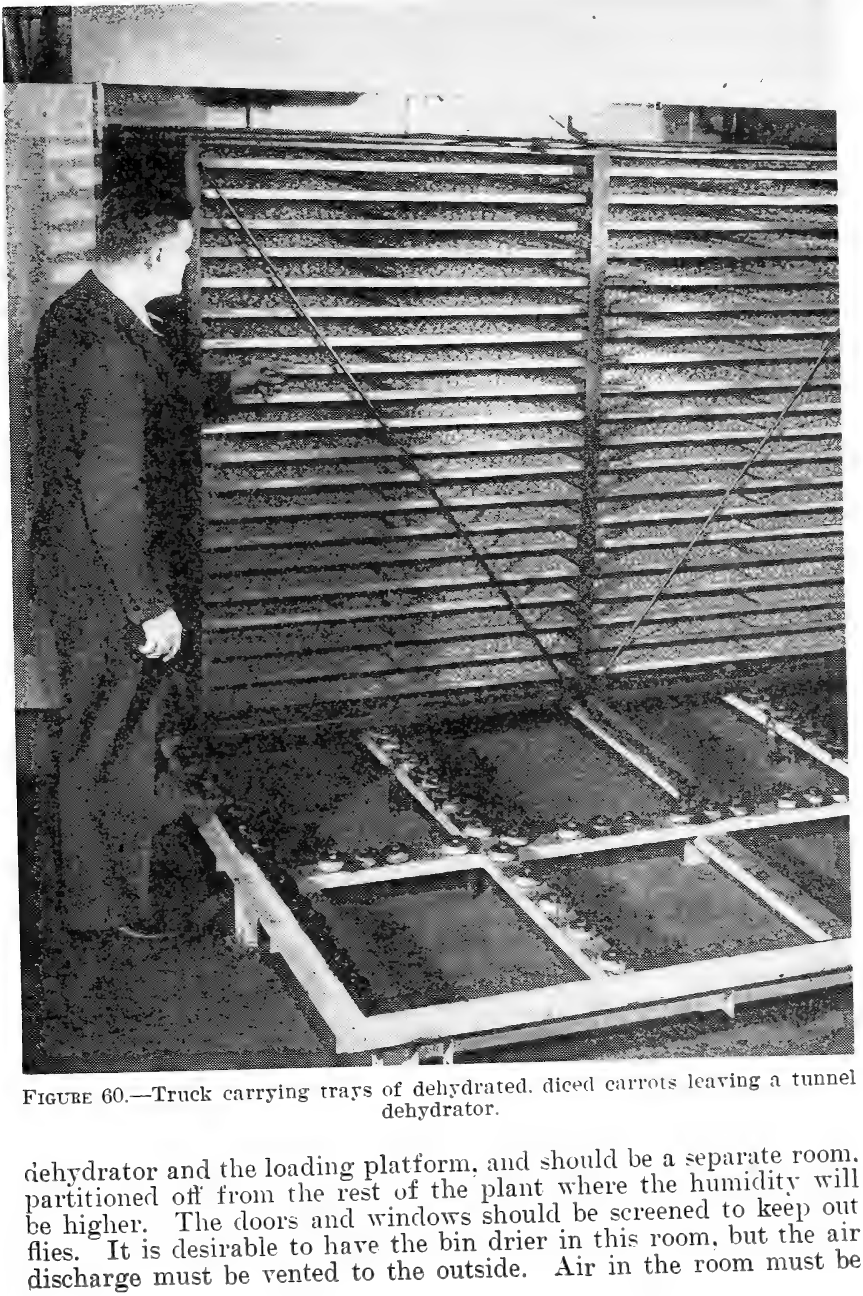

FIGURE 60.—Truck carrying trays of dehydrated, diced carrots leaving a tunnel dehydrator.

sufficiently dry so that as little absorption of moisture as possible occurs during packaging. In a dehydration plant with a capacity of 30 tons daily, one man does all the work from the end of the picking belt through the stacking of the cases.

Dehumidification of the air in the finishing and packaging room may be necessary. When exposed to air any dehydrated fruit or vegetable tends to increase or decrease in moisture content until it finally reaches an equilibrium content which is typical for that product and that relative humidity (table 9). Operators should consider carefully the advisability of dehumidifying the finishing and packing room in all cases where the moisture content at shipment corresponds to a relative humidity which is less than that which will occur in the packing room at any time of the year or of the day. This is important in handling leafy products and is most important when products of 3 percent moisture content or less are ground. The United States Weather Bureau publishes data on dew points which may be expected in various parts of the United States. If the prob-

TABLE 9.—*Selected data*[1]: *Equilibrium moisture content of various dehydrated foodstuffs*[2]

Product	Moisture content	Temperature	Relative humidity
	Percent	*°F.*	*Percent*
Apples	3	99	19
	5		29
	15		51
	26		63
Apricots	10	Room	50
	15		63
	26		72
Cabbage	4	99	20
	6		35
	10		49
Carrots	5	99	30
	10		48
	15		62
Eggs, whole	2	99	10
	4		29
	8		52
Flour, wheat, 83 percent patent	6	77	12
	10		40
	15		75
Milk, whole, 53 percent fat	2	77	32
	3		44–50
	5		50–70
Milk, skimmed, 1 percent fat	2	77	16
	3		24
	5		38
Peaches	10	Room	56
	15		66
Pears	10	Room	49
	15		63
	20		72
Potatoes, white	5	99	22
	7		38
Potatoes, sweet	4	99	19
	7		36
	15		62
Prunes	10	Room	35
	15		58
	26		68
Raisins	10	Room	37
	15		55
	26		65
Spinach	5	99	19
	8		38
Tomatoes	2	99	10
	4		19
	8		30

[1] See Anker, Geddes, and Bailey (*3*); Makower and Dehority (*30*); Schwarz (*40*); and Supplee (*42*).

[2] Data on dehydrated milk are significant in the storage and packaging of some soup mixtures, and data on eggs and flour are of interest for the sake of comparison.

able highest dew point can be estimated, the corresponding relative humidity in the packing room at any desired temperature may be determined from a humidity chart. (See p. 52.)

Some dehydrators in dry areas find that they can raise the air temperature in the packing room enough to avoid moisture absorption by the product. Warm air has a lower percentage of relative humidity than cold air of the same dew point. Besides the method just indicated, there are three methods commercially used for dehumidifying air, all of which actually remove a part of the water present. Silica and alumina gels are both used to absorb water vapor from air to be dried. The gels are reactivated by the use of closed steam pipes or electric heaters and a stream of air. Refrigeration is also used to condense moisture, which is separated thus from the incoming air. Another method consists of absorption of moisture in a spray chamber by special solutions, such as lithium chloride, which are regenerated after use. Finally, one must bear in mind that when the finishing and packing room is dehumidified by any method which actually removes water vapor from air, it may be practicable to remove some air from that room as the air feed to a bin drier.

FINAL INSPECTION OF THE DRY PRODUCT

Purchases of dehydrated vegetables for the several Government agencies are inspected by the Fruit and Vegetable Branch of the Food Distribution Administration, United States Department of Agriculture. Processing procedures are observed and recorded and the finished product is inspected for quality according to the specifications under which the purchase is made. Certificates are issued only when inspections are made on the sealed containers representing the shipment.

In order to facilitate inspection and as a direct aid to himself, the manufacturer should follow certain steps. The packaged material should be coded and warehoused by coded lots. The coding system used can follow any system desired but should impart the following information: Product, type, year, month, day, shift. Thus, if 100 five-gallon cans of julienne potatoes were produced on February 1, 1943, on the swing shift, they could be stamped PJ3B1A and warehoused together as a lot. This code can be stamped on the can, at the time the product is labeled, with a stamp pad and a water-insoluble canner's ink.

Coding entails very little actual expense but yields a great deal of valuable information. It enables the operator to keep an accurate running inventory of his production, and affords a basis for comparison of the efficiency of personnel and of the yields obtained from different lots, varieties, or sources of raw materials. It also enables the operator to find the source of trouble quickly, and affords a means of segregation, without jeopardizing the entire block, in the event that a particular part of the pack fails to meet specifications. Inspections are customarily made on carload lots.

Samples are drawn at the rate of approximately one container per hundred. The rate may vary according to the number of containers per individual code, the variations within the lots, and other factors. It is the inspector's responsibility to satisfy himself that any given lot meets the specifications and if any great variation is encountered more samples must be drawn.

When an inspection is made, representative samples are taken to a place in the plant where the containers can be opened and the opened product can be protected from moisture pick-up from the atmosphere. To facilitate inspection a table approximately 3 feet high with a top 6 x 3 feet and a hole 6 inches in diameter at one end is very advantageous. The top should have a light surface and be well lighted.

The condition of the container, the net weight, and the packing medium (such as an inert gas) are noted. The entire contents are removed from the can and mixed thoroughly. From the resulting mixture, a cross-section is taken to make a composite sample, which is sealed in previously dried jars. One to two such samples may be taken for such laboratory determinations as are required by the specifications. Examinations for defects, uniformity of size, presence of fines, and color of dry product can be made while the product is being weighed, and most of the material can be returned to the packer for repackaging. The inspector may also examine the raw product, plant sanitation, and packing procedures.

Laboratory analyses are made to determine the moisture content, enzyme inactivation, and reconstitution; other analyses, as outlined in the specifications under which the product is being graded, are also made. Upon completion of the inspection the results are forwarded to the contractor and purchasing agency. Loading for shipment will be supervised if such supervision is specified by the purchaser. Official certificates are issued and dated as of the day on which the analysis was completed. These certificates serve as a basis for payment when the merchandise is received and accepted.

Grades and Specifications for Fruits and Vegetables

United States grades for dried fruits are available through the United States Department of Agriculture, War Food Administration, Office of Distribution, Washington, D. C. Federal specifications for dried fruits can be purchased through the Superintendent of Documents, Washington, D. C.

At the present time United States grades and Federal specifications for dehydrated vegetables have not been issued. Purchases are made on Quartermaster Corps Tentative Specifications, which are obtainable through the Chicago Quartermaster Corps, 1819 West Pershing Road, Chicago, Ill., or Tentative FSCC Specifications obtainable through the Office of Distribution, War Food Administration, United States Department of Agriculture, Washington, D. C.

TEMPERATURE REDUCTION TO MAINTAIN QUALITY IN DEHYDRATED PRODUCTS

The quality of dehydrated vegetables can readily be injured before shipment by failure to reduce the temperature of packaged materials and to keep them cool. Holding dehydrated cabbage at 120° F. for a week, for example, results in almost complete spoilage. Measures must be taken to insure that such products will be cooled to 90° or less within 24 hours after drying has been completed. While they are on the inspection belt, freshly dehydrated vegetables cool to a considerable extent. Table 10 indicates the rate at which dehydrated potato strips cool when exposed to still air.

TABLE 10.—*Rate of decline in temperature of dehydrated potato strips exposed to air—single layer, 0.4 pound per square foot*

	Time of exposure in minutes—				
	0.0	0.5	1.0	2.0	4.0
	°F.	*°F.*	*°F.*	*°F.*	*°F.*
Temperature of potatoes	151	123	117	106	94
Temperature of air	74	74	74	74	74
Difference	77	49	43	32	20

As an example let us assume that the inspection belt for dehydrated potatoes is 12 feet long and moves 3 feet per minute. The temperature of the potatoes is 160° F. when they drop to the belt; that of the air is 70°. Time on the belt will then be 4 minutes. From table 10 we obtain an estimate of the temperature of the dehydrated potato leaving the belt. In this case the temperature would be 90° to 100°. With air at 85°, potatoes dropped on the belt at 150° would leave the belt after 4 minutes at 105° to 115°.

TABLE 11.—*Estimated cooling times for dehydrated julienne potatoes in 5-gallon square cans, standing alone—packed 13 pounds to the can*

Initial difference in temperature (° F.) between air outside and the center of the can	Time required to reduce differences in temperature to (° F.)—				
	40°	30°	20°	10°	5°
	Minutes	*Minutes*	*Minutes*	*Minutes*	*Minutes*
50	70	160	290	510	730
40		90	220	440	660
30			130	350	570
20				220	440
10					220

Measurements of the temperature of vegetables should be made after they have cooled on the belt. Such measurements can be made by thrusting a thermometer into the center of a filled carton or can and by allowing 10 minutes before the reading is made. Measurements on rate of cooling of potato strips in cans have demonstrated that the center of a full 5-gallon can when filled at 105° F. and placed in air at 85° will cool to 90° in 7 hours. Estimated cooling times for dehydrated potato strips in 5-gallon square cans, standing alone, are shown in table 11.

The estimated time required to cool the same potato strips in 5-gallon-size lead-foil packages placed in outer cartons approximately 13½ x 7½ inches in size is the same as for the metal cans (*38*). If the cartons are stacked back to back on their sides, in a stack two cartons thick, the estimated time required to cool the contents from 105° to 90° F. at the central plane of the stack with air at 75° is 7 to 8 days. Similarly, for a stack that is four cartons thick the estimated time is 4 to 5 weeks (*41*).

Cartons and cans should be kept apart or unstacked, as far as possible, until they are cooled to 90° F. or lower. A period of several hours may be needed. Temperature of the air is of course a factor. Canners commonly make use of cooling rooms. When dehydrated vegetables are shipped from a cool area through a hot one, close packing will be helpful provided the cases when shipped are close to the air temperature at the point of shipment.

The heat-diffusing and heat-conducting properties of various dehydrated foods have been measured recently at the Western Regional Research Laboratory. The measurements on strips of dehydrated white potatoes, which are representative, approach the corresponding properties of sawdust, which is used commercially as a heat insulator. Cooling rates are directly proportional to the diffusivities. When the containers are cans, the average diffusivity is increased to about three times that of dehydrated vegetables in foil-protected cartons. This is because the steel sheets are highly conductive and will aid in the removal of heat from the stack. No such increase in the rate of cooling occurs in unstacked, single cans, since the steel is on the outside and at once comes to room temperature.

The peaks of storage rooms should be ventilated in summer and cases should not be stored next to the roof. In a warehouse thus ventilated, a pronounced increase in temperature from the ground level upward has been observed. The outside air was 85° F., that at the floor level was also 85°, at a point 8 stacks high it was 93° and 6 feet above it was 98°.

STANDARD TYPES OF PACKAGES

Government specifications define several standard types of packages for use in the exportation of dehydrated vegetables and fruits to the armed forces and to lend-lease nations, but for domestic use "commercial packages" are specified. Export containers, particularly for military use, are designed to be used under average temperatures of as high as 90° F. at a relative humidity of 90 percent, and at occasional temperatures as high as 120° and as low as −15°. The package and contents may be exposed to rain or even immersed in water on being landed from ships. Dropping of cases during handling is three to five times as severe during export for military use as in domestic use. The cases must be capable of withstanding 120 to 200 drops of from 1 to 3 feet without damage. The package must not allow the contents to increase more than 2 percent in moisture content per year even when the humidity of the surrounding atmosphere remains constantly at 90 percent. Packages that contain dried vegetables packed in an inert gas must allow no air to enter nor gas to escape; that is, they must be hermetically sealed.

Ten types of packages are described below and the approximate numbers of containers required for dehydrated vegetables are shown in table 12. Types 1 to 5 are tin or steel cans, of designs that can be hermetically sealed, excluding moisture vapor, water, air, and insects. Types 6 and 7 are laminated lead-foil, heat-sealed packages. In order to free steel for other purposes and to lessen the demand for tin, substitute containers of high moistureproofness have been developed. For the less hygroscopic dehydrated vegetables and fruits, for example dry, shelled beans and evaporated apples, standard packages for export (type 8) consist of heat-sealable laminated cellophane, or

TABLE 12.—*Estimated container requirements for dehydrated vegetables*[1]

Vegetable	Form	Weight per 5-gallon	Over-all shrinkage ratio	5-gallon containers required per ton of raw untrimmed vegetables
		Pounds		*Number*
Beets	3/16-inch slices	10.0	13–16 to 1	12–15
Do	3/8-inch cubes	17.0	13–16 to 1	7–9
Cabbage	Shreds	7.0	13–22 to 1	13–22
Carrots	3/8-inch cubes	17.5	14–16 to 1	7–8
Onions	Flakes	12.0	12–15 to 1	12–15
Potatoes, white	3/8-inch cubes	16.0	5–8 to 1	12–25
Do	Strips	10.0–15.0	5–8 to 1	17–40
Rutabagas	1/4-inch slices	12.5	6–10 to 1	16–27
Sweetpotatoes	do	12.0	4–6 to 1	30–40

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[1] No standard loadings per container have been established. Among the vegetables, sweetpotatoes require more containers per ton of raw material than are required by the other vegetables; however, a 50-ton plant requires only 1,500 to 2,000 5-gallon cans or cartons per 24 hours, or 60 to 80 per hour. Because of this low requirement, highly mechanized packaging lines have not been used with 5-gallon containers.

laminated cellophane-to-glassine bags in which a degree of moisture-vaporproofness results from the use of lacquers and a plastic laminating agent. These packages are less likely to be attacked by most tropical insects if no food particles are left on the outside of the package. Food particles stimulate boring by the insects and perforation of the lining of the package may result.

For cut sulfured fruits with a moisture content of approximately 25 percent, strips of paper are used to line the boxes (type 9). For pasteurized fruits, such as prunes, the largest standard package is the vacuum 5-pound can (type 10).

Type 1.—The 5-gallon square can is approximately 9⅜ inches in width and 13⅞ inches in height, and weighs 2.4 pounds. The tin plate used in these cans consists of 107 pounds of steel and 1.25 pounds of hot-dipped tin per base box. (A base box consists of a bundle of 112 sheets 14 x 20 inches.) Provision is made in current specifications for the use of electrolytic tin plate containing 0.5 pound of tin per base box for the entire can or for the side walls. The stud hole is 6⅞ inches in diameter. Where hermetic seals are required for gas packing, lids may be soldered or the newer compound-coated lids may be used in conjunction with double or single seamers. These must be of approved design.

Type 2.—Thirty-pound frozen-egg or fruit cans were permitted by the United States Army Quartermaster Corps for some vegetables until replacement foil containers came into use.

Type 3.—The 5-gallon round steel can with a clamping ring has been used as a temporary package. Its relative cost and weight are high for single-trip packages.

Type 4.—Some use has been made of No. 10 round, sanitary, hermetically sealed cans with a tin-plate body (107 pounds of steel and 1.25 pounds of tin per base box) and ends of black plate. Other combinations that reduce the tin requirement are also used. The side seam is soldered, while the end seams are closed by compound and double seaming.

Type 5.—The No. 2½ round can, hermetically sealed, contains the same types of materials as type 4.

Type 6.—This is a foil-protected package consisting of (1) 5-gallon inner carton that is 13 x 6½ x 14 inches in outside measurement with taped joints, and consists of solid sulfite, kraft, manila, or corrugated kraft, (2) sealed laminated envelope consisting of kraft, asphalt, lead foil, and heat-sealing cellophane, which covers the inner carton, (3) a protective strip of chipboard, and (4) a weatherproof solid-fiber outer carton.

Type 7.—This is a smaller foil-protected package consisting of (1) various permitted liners in contact with the food, (2) a laminated sheet containing lead foil, made up as a heat-sealing bag outside of the liner, and (3) a chipboard carton. An alternate package consists of an inner bag of amber glassine waxed at the rate of 25 to 55 pounds per ream, a kraft-lined chipboard carton and a double overwrapping of paper with a basic weight of 20 pounds plus 30 pounds of wax per ream. These are packed in solid fiber cartons.

Type 8.—This is one of the optional soup packages and resembles a cereal container. It consists of an interlining bag of amber glassine with 30 pounds of wax per ream and an outer carton of bending chipboard. The carton is double, overwrapped with paper that has a basic weight of 20 pounds and is coated with 30 pounds of wax per ream.

Type 9.—In normal times and when hazards are not severe, evaporated apples, dried prunes, apricots, and figs are exported in paper-lined wood boxes containing 25 pounds net weight, and dates are shipped in flat boxes containing 15 pounds. Domestic boxes hold 10, 25, and 50 pounds of dried fruits. Uncut fruits, such as prunes, raisins, and apricots, are graded into various sizes, which are packed separately. Federal packaging specifications are available for most dried fruits.

Type 10.—Dried fruits are shipped abroad for the armed forces in No. 10 cans, hermetically sealed, and sometimes evacuated. Evaporated or dried apples, apricots, pitted dates, figs, peaches, prunes, and raisins are packed at rates varying from 4 pounds per can for evaporated apples to 7 pounds per can for prunes and figs. Six cans are packed in each wood case.

PACKAGING EQUIPMENT AND METHODS

After final inspection and culling, dehydrated vegetables and fruits are packaged. If they are to be powdered, a hammer mill will be needed, and also a dehumidifier if the atmospheric humidity in the room is high. Vibrators are often used in packing to produce a higher bulk density. A simple type consists of a low platform, set diamond-shaped with the pivot placed diagonally. Strips along the two back edges form a stop for the cans. Power is supplied by a ⅓-horsepower motor operating at a few hundred revolutions per minute. An eccentric is mounted on a low-speed shaft and this is connected to the back corner of the platform by a rod. In another type, a spring-mounted platform is vibrated by a cam in the motor shaft. The vibrator can be equipped with a weighing scale. Weighing scales should have a 50-pound range, an attachment for indicating the amount over or under, and a tare weight.

Gassing is required for cabbage or carrots that are to be sold under Government contract (fig. 61). Flavor, color, and vitamins are retained through the elimination of air and its replacement with nitrogen or carbon dioxide. Vacuum packing is not used because 5-gallon cans require a very solid fill if they are to be sealed under vacuum. A maximum limit of 2 percent of oxygen is recommended for sealed, gas-filled containers, and the analysis should be made at least 12 hours after the cans are filled and sealed. Air can be displaced to a point at which the oxygen content is below 2 percent by the use of (1) the cylinder-and-meter method, (2) the vacuum-chamber method, or (3) the carbon-dioxide-snow or "dry ice" method. Equipment and methods for the analysis of atmosphere in cans are described on page 157.

Cylinder-and-Meter Method

The most common method of removing air has been by the use of gas run from a cylinder through a reducing valve, a rubber tube, and a metal purge tube thrust to the bottom of the can. The amount of gas is controlled by the pressure setting of the reducing valve, the duration of the gas flow, and the occasional testing of the gas at the top of the can with a burning match. If the match goes out, the can is considered to be sufficiently low in oxygen content. While this method commonly results in analyses below 2 percent of oxygen, the time is not accurately measured and the cans have been found to contain as much as 8 percent of oxygen.

Tests have shown that the introduction of an iron-case dry-gas meter, of stock design, between the cylinder and purge tube improves the method. The stock meter used in testing had one dial that measured 1 cubic foot per revolution. In the displacement of air by this method, the lid of the can is placed over the opening; the can is gassed and, after removal of the tube, the lid is attached to the can by seaming to form an hermetic seal. Soldering is an effective method of closing cans but is a slower method than seaming. The following results have been obtained in tests of the cylinder-and-meter method of gassing:

FIGURE 61.—Filling 5-gallon cans with diced dehydrated carrots.

Cubic feet of gas:	*Time (seconds)*	*Oxygen content of can (percent)*
2	60	0.8–1.0
1	30	1.2–1.6
1	10	1.8–2.4

These results were obtained with dehydrated cabbage and carrots at typical loads per can.

Vacuum-Chamber Method

Another process of removing air from 5-gallon cans and replacing it with carbon dioxide or nitrogen can be termed the vacuum-chamber method. This method requires equipment similar to that required in vacuum canning. One type of equipment has a flat plate with a space on it for one or more cans. Cans are placed on the plate and are covered by a heavy metal chamber or bell provided with a counterpoise. For the evacuation of the air in a chamber, a vacuum pump is provided. The effectiveness of the equipment depends largely on the closeness of the joint between the chamber and the plate, which governs the leakage of air inward, and on the degree of vacuum to which the pump can exhaust the air in the chamber and the can or cans thereunder.

For a single-unit chamber the pump should have a capacity displacement of 100 cubic feet per minute, and should produce a vacuum of 29.5 inches of mercury. The highest degree of vacuum can be attained by the use of any of a number of rotary pumps. The next type of pump, in order of attainment of vacuum, is the two-stage steam ejector. At least 75 pounds per square inch of steam pressure is necessary for efficiency. The first cost is lower than those of rotary or reciprocating pumps, but the demand on steam between evacuations diminishes the utility of this device. Single-stage reciprocating pumps will not produce the required vacuum, but double-stage reciprocating pumps will. Some double-acting reciprocating pumps can be easily and inexpensively converted to double-stage pumps.

Modern gassing chambers of the bell or horizontal type hold the lid away from the can during the operation by means of an externally operated chuck or by an electromagnet. The procedure is carried out as follows: The can is filled with a weighed amount of dehydrated vegetables, and a lid is set in place. The chamber is closed. A vacuum of at least 29.5 inches is drawn on the chamber and this will take 20 to 40 seconds. The valve to the vacuum pump is then closed, and a valve to the cylinder of gas is opened, releasing the vacuum. A pressure of 1 to 2 pounds per square inch is built up in the bell, which will prevent the entrance of air when the chamber is opened. The chamber is opened and the can is removed and hermetically sealed immediately. Cans should be handled by the corner edges, since any bellows action of the sides caused by handling will draw air into the can before it is sealed.

In practice, the time for evacuation is 20 to 40 seconds, for breaking the vacuum about 20 seconds, and for a cycle including opening and closing of the chamber and sealing a pair of cans, about 90 seconds. In tests oxygen content of the atmosphere in cans of carrots and cabbage sealed by means of a double-stage reciprocating pump, with a 29.5-inch vacuum, and one chamber, was found to be 0.5 to 1.6 percent. Three to four cans may be evacuated, gassed, and sealed per minute in modern-type machines (fig. 62).

Gassing by Means of "Dry Ice"

The solid carbon-dioxide snow or "dry ice" method has been developed at the Western Regional Research Laboratory as a means of gassing carrots or cabbage with a minimum amount of equipment. The method has not yet been tried out commercially. Unlike water ice, dry ice changes directly into a gas when it is heated. It is shipped in 50-pound blocks, packed in quadruple corrugated cartons. Losses in shipment and storage are approximately 10 to 6 percent per day, respectively. Suitable storage bins can be made with hardwood frames, sheet metal, or plywood walls for the lining, 6-inch layers of cork or other insulation on the bottom and sides, and a 4-inch-thick kapok, duck-covered pad as the cover.

One-fourth pound of ground dry ice is placed in the bottom of a 5-gallon can and distributed uniformly. Then the vegetable is weighed into the can, which is placed in a water trough equipped with a conveyor, and the lid is placed on the opening in the can. At once an evolution of carbon dioxide takes place and the air, and later the gas, escapes around the lid. Two cubic feet of gas is formed in the sublimation of the dry ice. After 6 to 12 minutes in water all the solid carbon dioxide will have gasified and the can is capped after a short period of standing in the air.

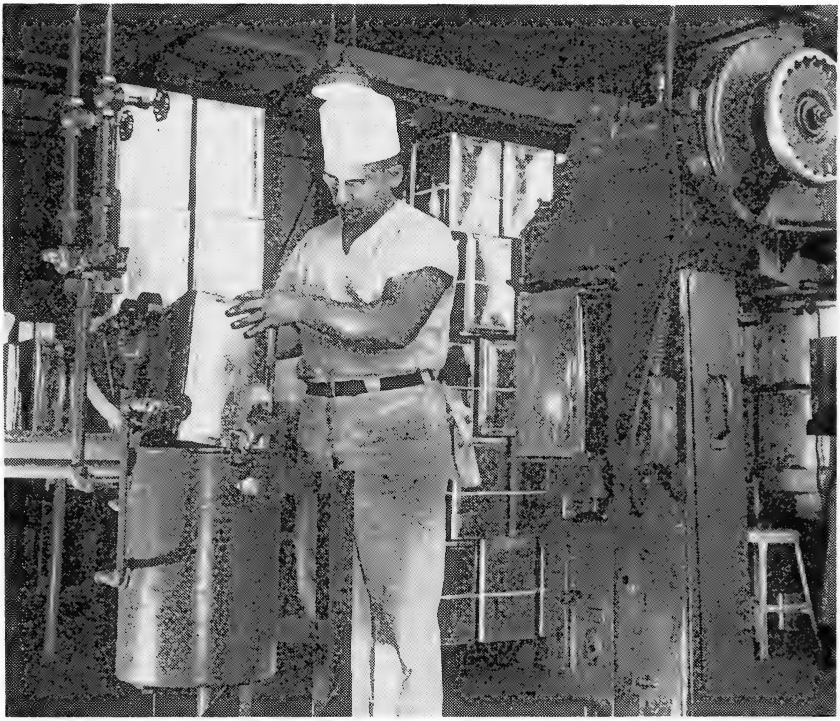

FIGURE 62.—Replacing air with carbon dioxide in a can of dehydrated carrots. Operator is placing a 5-gallon can in a vertical-type evacuating and gassing chamber at left. Sealing machine is at right.

The atmosphere in 5-gallon cans of cabbage or carrots has repeatedly been brought to 0.8 to 1.0 percent oxygen by this method. Care must be taken to avoid the sealing of cans in which ungasified dry ice is present; dry ice in a sealed can will cause cans to bulge later. The ordinary precautions for handling dry ice should be observed.

Sealing

Dehydrated vegetables and fruits that are packaged in tin cans are hermetically sealed, even when packed in air. Formerly the stud hole was covered with a lid and a tight joint was made by soldering, but more recently, because of the shortage of tin and the lower percentage of tin in solder, the trend has been toward the use of square cans with mechanically formed seams. These seams are of two types, double seam and single seam. With both a sealing compound is used on the surfaces subject to closure, in order to produce an hermetic seal. An hermetic seal may be tentatively defined as one that is gasproof, moistureproof, and bacteria-tight, both initially and throughout a common period of handling and storage. Shipments of 5-gallon cans of dehydrated products are frequently made across mountain passes 7,000 feet high; in a trip of this sort a sealed can filled at sea level would be subjected to 3½ pounds per square inch of internal pressure. Tests show that when a leaky can is packed with carbon dioxide at sea level, shipped over a 5,000-foot pass, and returned to sea level, the oxygen content may be expected to increase 4 percent.

Seaming machines for 5-gallon square cans have been developed by several companies and can be leased. Machines will seal at rates between 6 and 18 cans per minute (fig. 63).

Packaging in Cartons

The equipment and methods recommended for cartons vary somewhat from one supplier to the other. An inner carton of banding chipboard must be assembled and taped at the bottom, and the carton is then filled and the top is taped. A lead-foil bag is expanded into shape on a mandrel and the filled carton is slid into the bag on an inclined chute. The package is placed in an erect position and passed on a roller conveyor through a heat sealer, where the envelope is deflated by suction or other method. The "ears" of the envelope are folded over, a strip of folding U-shaped chipboard is placed over the bottom and the sides, and the unit is thrust into the outer carton, which is then sealed, and the seams at the end are covered with cloth tape.

Labeling Packages and Cases

The labeling of packages is described in Government contracts, which in general require the name and type of product, the net weight in pounds, the month and year of dehydration, name of packer, location of processing plant, and specific directions for rehydration. Part of the foregoing is repeated on the packing cases.

It is important that finished boxes be stenciled daily; if for example inspection reveals too high a moisture content, the number of cases involved will be fewer if only 1 day's product has been grouped and stenciled together.

Cases

Materials for cases and methods of packaging are included in Government specifications. For overseas shipment, packing cases undergo 3 to 5 times as much handling as for domestic shipments. A loaded case that withstands 40 drops of 1 to 3 feet in a tumbling drum 7 feet in diameter is safe for domestic use, but must withstand 120 to 200 drops for export shipment. Exposure to rain and immersion of cases in salt water during landings are 2 more conditions that frequently must be withstood.

SUBSTITUTES FOR TIN-PLATE CONTAINERS

Wartime shortages of steel and tin have stimulated a search for containers that will successfully replace tin plate in the packaging of dehydrated foods. The substitute container must be one that ap-

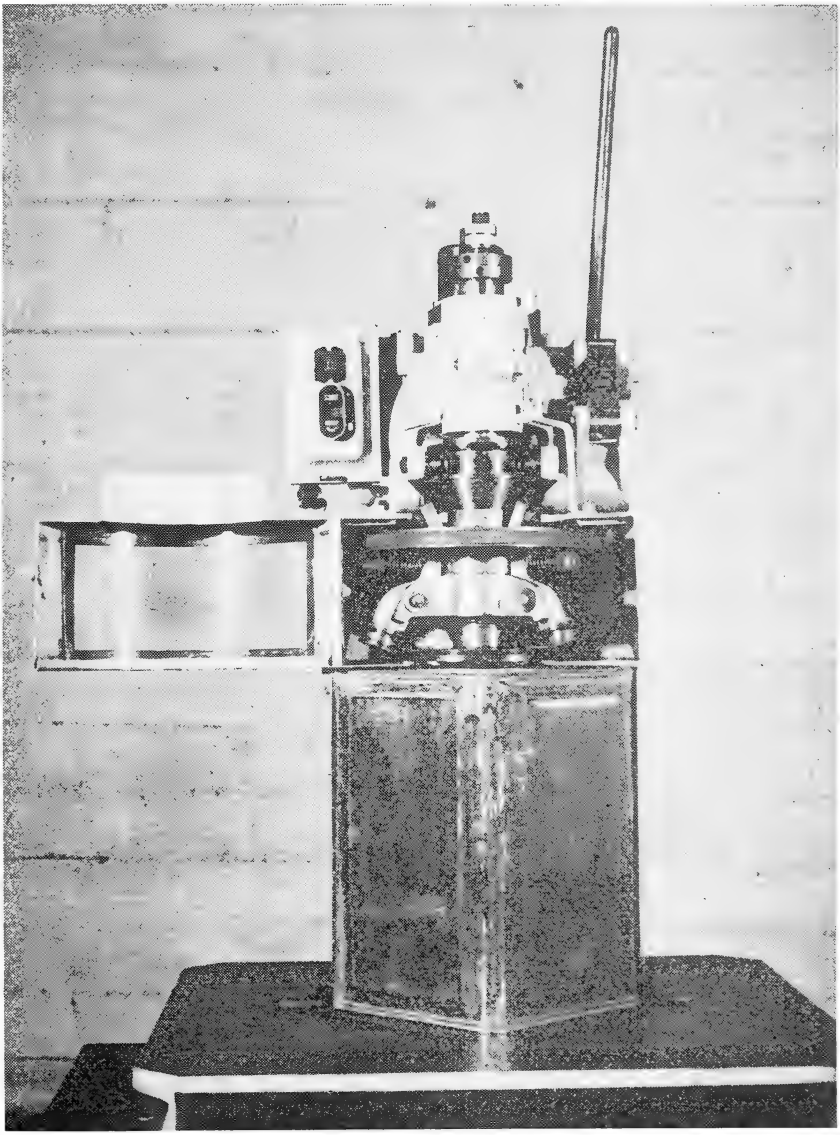

Figure 63.—Sealing machine which forms a 20° angle, hermetic seal on cans.

proaches or meets the standards set by tin-plate containers. These standards are (1) hermetic sealing, (2) durability, and (3) prevention of transmission of light. Glass containers can be sealed hermetically but fail to meet other requirements. Flexible materials, such as heavy treated papers, moistureproof cellophane, simple laminations of paper and cellophane, and compound laminations of paper, cellophane, and metallic foils, have certain advantages and disadvantages as packaging materials and, if handled appropriately, can be used satisfactorily.

Functions of the Package

Since all unprotected dehydrated foods absorb moisture from the atmosphere, it is essential that the package be moistureproof. The speed of absorption of dried vegetables varies considerably, because of differences in composition of products and also differences in the extent to which the food has been dehydrated. For example, cabbage dehydrated to 5 percent moisture content is more hygroscopic than potatoes containing the same amount. Also cabbage that contains 5 percent of moisture will absorb moisture more rapidly than cabbage that contains 10 percent. Excessive absorption of moisture by dehydrated foods causes chemical changes that quickly impair appearance, palatability, and nutritive values. A suitable high standard for long storage, one that is commonly used, is this: Sufficient moisture-vapor resistance to prevent a maximum absorption of 2 percent of moisture during a storage period of 1 year.

In a consideration of substitutes for the metal or glass hermetically sealed container, a number of factors that affect moisture-vapor permeability must be evaluated. The principal factors are as follows:

The nature and type of the protective materials.—Some materials show a greater moisture-vapor resistance than others. Laminated or compound-laminated sheets are more moisture-resistant than single sheets.

The ratio between the area of the package and the weight of the food contained in it.—The greater the package surface exposed per given weight of hygroscopic food material, the greater the absorption; that is, well-filled packages of hygroscopic food materials permit the absorption of less moisture per given weight of contents than partially filled packages.

Length of time the package will be exposed to humid atmospheres.—The amount of moisture absorbed through a material is in direct proportion to the time of exposure.

Leakage of moisture through package wall due to defects.—Thin spots or holes in coatings on materials permit the passage of moisture vapor.

Leakage of moisture vapor through breaks in the protective films caused by rough treatment.—Some moistureproof films are inelastic and their efficiency is impaired by abuse, which causes breaks in the continuity of the film.

Leakage due to poor sealing properties or careless sealing.—Some thermoplastic coatings do not make a firm bond after heat sealing, and as a result the seams open. Improper sealing temperatures or technique may result in faulty seals.

Leakage due to destruction of the coating during heat sealing.—Heat sealing at excessively high temperatures may impair the adhesive properties of thermoplastic coatings or cause sufficient decomposition to affect moisture-vapor resistance.

The moisture-vapor differential between the inside of the package and the storage atmosphere.—Since dehydrated foods are hygroscopic, the relative humidity within the package is usually low. Packages are stored in atmospheres of high relative humidity. The attraction for moisture within the package is quite marked and the amount of moisture absorbed is directly proportional to the difference between the internal and external relative humidities.

Rate of circulation of air in the storage space.—The circulation of humid air across the surfaces of packages increases the rate of moisture absorption through the packaging material.

Single Sheets, Double Laminations, and Compound Laminations

A single-sheet substitute material to take the place of tin-plate or other hermetically sealable containers has not been discovered. For example, a close-textured paper heavily waxed on both sides satisfies all of the requirements with the exception that rough treatment seriously impairs or destroys its efficiency. Laminations of two or more sheets of similar or different characteristics will frequently offset the weaknesses of single sheets.

Such laminations as glassine paper to cellophane, cellophane to parchment paper, cellophane to cellophane, and other combinations show increased resistance to the passage of moisture vapor as compared with single sheets. With some laminations the increase in resistance to moisture is due to the thermoplastic adhesive used to cement the materials together. If the membranes are subject to "pinholing" or other imperfections during their manufacture, the adhesive seals the imperfections during the process of lamination.

Far superior to double laminations is the recently developed compound lamination that includes a metal foil, which is an extremely moisture-vapor resistant material. Kraft paper is laminated to the foil with asphalt on one side and cellophane with thermoplastic adhesive on the other side (fig. 64). This compound structure protects the lead-foil sheet against pinholing or rupture due to flexing and other stresses. The finished laminated sheet has strength, waterproofness, resistance to moisture vapor, lightproofness, and exceptional heat-sealing properties. Its heat-sealing properties are due in part to the lacquer coating on the surface of the cellophane, and the seal strength is further enhanced by the thermoplastic coating applied to the inner cellophane surface. Its unusual moisture-vapor resistance is due to the multiple barrier that it presents. In order to pass through this structure, moisture vapor must penetrate kraft paper, asphalt, lead foil, thermoplastic adhesive, and moisture-vaporproof cellophane.

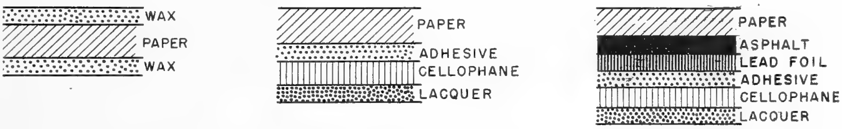

Figure 64.—Construction of laminated packaging materials.

In use, this material is first fashioned into flat envelope-type bags. Before these bags are filled they are shaped by the use of a mandrel. After they are lined and filled, a partial vacuum is created in the container by means of suction and the bags are quickly and securely heat sealed. The sealed package is placed in an outer shipping container. This package has been found to approach closely the standards set by the hermetically sealed tin-plate container and, when the closure has been carefully completed, it complies with virtually all of the requirements necessary to protect dehydrated foods against deterioration caused by absorbed atmospheric moisture.

The use of the less efficient packaging materials is always fraught with danger. However, certain of the less hygroscopic products can be packaged in less efficient materials, especially if they are to be held only a short period. With the less hygroscopic foods, such as certain of the dried fruits, and especially those with moisture contents 10 or

15 percent above those permissible with vegetables, the high standard of efficiency is not required.

None of the membrane or laminated-membrane packages will prevent the penetration of all insects, nor are they proof against the attacks of rodents. But properly dehydrated vegetables are too dry to support insect life. Eggs will live in the packages, however, and will hatch if moisture becomes available. Dried fruits, on the other hand, commonly contain sufficient moisture to maintain insect life as well as microbial activity, and special sanitary precautions are required during packaging.

Glaze Packaging for Compressed Dehydrated Foods

Current investigations have shown that the packaging of compressed dehydrated vegetables by the application of a glaze of moistureproof thermoplastic material is entirely feasible. After the food is pressed to the desired density, the dehydrated product is tightly wrapped in heat-sealable membrane, such as waxed paper or heat-sealing cellophane, and is then dipped into a molten mixture of thermoplastic waxes, which upon cooling solidify to a firm continuous film that protects the food against absorption of moisture and contact with air.

COMPRESSION TO HIGH DENSITY FOR PACKAGING

In addition to the saving in shipping space that results when foods are dehydrated, futher saving can be achieved by compression. When a ship is loaded with cargo at the rate of 1 ton per 40 cubic feet, the holds are filled and at the same time the ship carries a full load. The objective in the compression of dehydrated foods should therefore be 55 to 60 pounds per cubic foot as the minimum density. This calculated objective takes into account the fact that the finished package is a little less dense than unpackaged cakes. Investigations have shown that such densities can be attained without loss of quality in the reconstituted product.

Even higher densities are to be preferred if an oxygen-sensitive product is compressed and packaged in hemetically sealed containers. Dehydrated cabbage, carrots, and tomato-juice cocktail are examples. The denser the pack, the lower will be the ratio of oxygen in the can to the dry fruit or vegetable.

A further advantage of compression is the diminished tonnage of steel and tin required when cans are used, since doubling the density halves the metal required. The percentage of saving in cans resulting from compression is numerically equal to the percentage of reduction in bulk (table 13, column 9).

In addition to increased density, rehydration to original size and shape is an objective, with a low percentage of fines or small particles. In tests, fines that pass through a 4-mesh screen after rehydration have been kept under 5 percent. Weighed samples of blocks were rehydrated and screen analyses made of the cooked product. The low percentage of fines prevents a mushy texture and maintains palatability equal to that of unpressed, rehydrated products. The table shows the conditions under which fruits and vegetables have been compressed with 5 percent or less of fines. The time required for reconstitution is not increased over that required for unpressed foods.

High densities in the pressed block require higher pressure when

TABLE 13.—*Compression of dehydrated fruits and vegetables*

Fruit or vegetable	Moisture (percent)	Temperature of pressing (° F.)	Pressure for blocking (lbs. per square inch)	Densities (pounds per cubic foot) [1]			Approximate content of packages (lbs. per 5-gallons)	Reduction in bulk (percent) [2]
				Initial	After compression	Compression ratio (to 1)		
1	2	3	4	5	6	7	8	9
Apple nuggets	2	170	450	12.5	64	5.1	12.0	71
Do	2	75	850	12.5	53	4.2	12.0	64
Apricot halves	25	75	150	42.0	79	1.9	28.0	44
Beet cubes	4.1	160	650	25.0	62	2.5	17.0	57
Beet slices	5.7	120	650	12.5	64	5.1	8.0	80
Beet strips	4.2	120	650	15.0	57	3.8	10.0	72
Carrot cubes	5.2	160	650	19.0	62	3.3	17.5	50
Carrot slices	4.8	160	650	6.0	56	9.3	8.0	75
Carrot strips	3.7	160	650	10.5	47	4.5	10.0	62
Onion flakes	3.0	140	650	6.0	61	10.1	12.0	60
Prunes, whole	28.0	75	150	48.0	78	1.6	36.0	27
Rutabaga slices [3]	6.9	140	850	11.0	59	5.4	12.5	68
Tomatoes, spray-dried juice [4]	4.0	78	1,500	30.0	60	2.0	27.0	31

[1] Densities before compression were measured on shaken but unpressed material (column 5). Densities of commercial shipments are frequently higher.

[2] The percent reduction in bulk equals the difference between the weights of a 5-gallon can of compressed vegetables and the corresponding weight of the uncompressed vegetable divided by the former weight. In computing the net weights of packages of the compressed foods, allowance is made for 15 percent of unused space in cans and for 5 percent in cartons.

[3] The tentative moisture content of rutabagas is 5 percent, at which blocking will produce a lower density than that found.

[4] Spray-dried tomato-juice cocktail is packed 4 pounds per No. 10 (3 quarts) can.

the dried fruits and vegetables are low in moisture content. Furthermore, with less moisture content any given pressure will produce a higher density and a more cohesive block if the dried product is hot instead of cold. The densities shown in the table were measured on disks one-half to three-fourths inch thick. These disks were kept in cans without wrapping while they cooled, with the exception of onions and carrots, beets, and rutabagas, which were pressed into 1-pound blocks 2¼ inches thick and were cooled in a holding press. With onions, beets, rutabagas, and carrots it has been found that blocks tightly wrapped in cellophane, with the wrapping sealed, need not be kept in a press to cool. During the cooling the densities under such conditions decrease from 61 to 59 pounds per cubic foot for onions and from 62 to 58 pounds for carrots.

Sun-dried apricots, cut and pitted, can be compressed by hand at room temperature to a bulk density of 42 pounds per cubic foot. A pressure of 150 pounds per square inch at room temperature has resulted in a density of 79 pounds per cubic foot. Higher pressures and an elevated temperature are required for high densities when fruit products are dehydrated to as low as 2 or 3 percent moisture content. The table shows data on apple nuggets for which, because of a 2 percent moisture content, a pressure of 450 pounds per square inch and a temperature of 170° F. were required to produce a block density of 64 pounds per cubic foot. At 75°, 850 pounds of pressure was required to produce a density of 53 pounds per cubic foot.

For the K rations used in the Army, fruit bars with 20 percent moisture and containing glucose are made by extrusion from machines of the sausage-making type on a belt where the bars are cut to length.

These machines use a worm screw to force the fruit paste through a tapered nozzle. Determination of a suitable taper for a particular product requires some experimentation. The bars are wrapped after cutting. If they are to be pasteurized, a suitable wrapping consists of a layer of greaseproof paper for use in handling, a cellophane bag that is heat-sealed after insertion of the bar, and a light chipboard box. A typical pasteurized fruit bar packaged in this manner has a density of 80 pounds per cubic foot.

The maximum attainable density of dried fruits and vegetables can be estimated from (1) existing analytical data on their pulps and (2) data on the densities of their constituents. For dried peaches the estimated attainable density is about 75 pounds per cubic foot at 20 percent moisture content, or 85 pounds if free from moisture.

Presses and Processes

Hydraulic presses have been used in Germany for the compression of mixed vegetables, herbs, carrots, cabbage, and dried sauerkraut. Continuous tile presses are reported to be in use, in which pressure is imparted by two cams acting at different stations in the machine. Knuckle-joint presses are used in the United States to compress hops, and screw presses are in use for compressing dehydrated-egg powder. Some free-flowing powdered soups have been smoothly handled in industrial tableting machines on an experimental basis. The latter are not well suited for use in forming blocks of dehydrated vegetables because: (1) The vegetables are not free-flowing, and therefore automatic and uniform charging of the molds cannot be accomplished in typical machines; and (2) such tableting machines ordinarily operate at compression ratios of 2 to 1, or less. The compression ratio is the ratio of the volumes of the filled mold before and after compression. It can be computed by dividing the density after compression by that before compression. Column 7 in the table shows such ratios. Press makers must know the compression ratio in order to determine the length of stroke of the ram (fig. 65).

The capacity of a press is usually stated in terms of the total safe working pressure between the platens. Molds may have one cavity or multiple cavities. Dried fruits and vegetables have been formed into blocks 6 x 3 x 1 inches in size. Blocks 2¼ inches thick have been formed and a brick approximately 6½ x 4½ x 2¼ inches with 1 edge rounded has been proposed, since it lends itself well to packing in standard 5-gallon cans at the rate of 16 blocks per can. Such a block weighs 2 pounds and can be reconstituted into 50 servings of carrots (fig. 66). Military recipes are in terms of 100 servings (*43*) for companies, and probably the most suitable blocks should contain weights corresponding to this number of servings. Blocks can also be formed with indented scorings like those on milk-chocolate slabs to facilitate breaking the blocks into smaller units of known weight.

To reduce friction, the surfaces of molds must be very smooth, a condition which can be produced by a surface grinder. It is frequently the practice to follow this by nickel or chromium plating and polishing. The surface of new dies must be lubricated with salt-free, moisture-free, edible oils or fats such as commercial hardened shortenings or special edible lubricants. Continuous use of lubricants may be required to reduce the friction as the fruit or vegetable moves

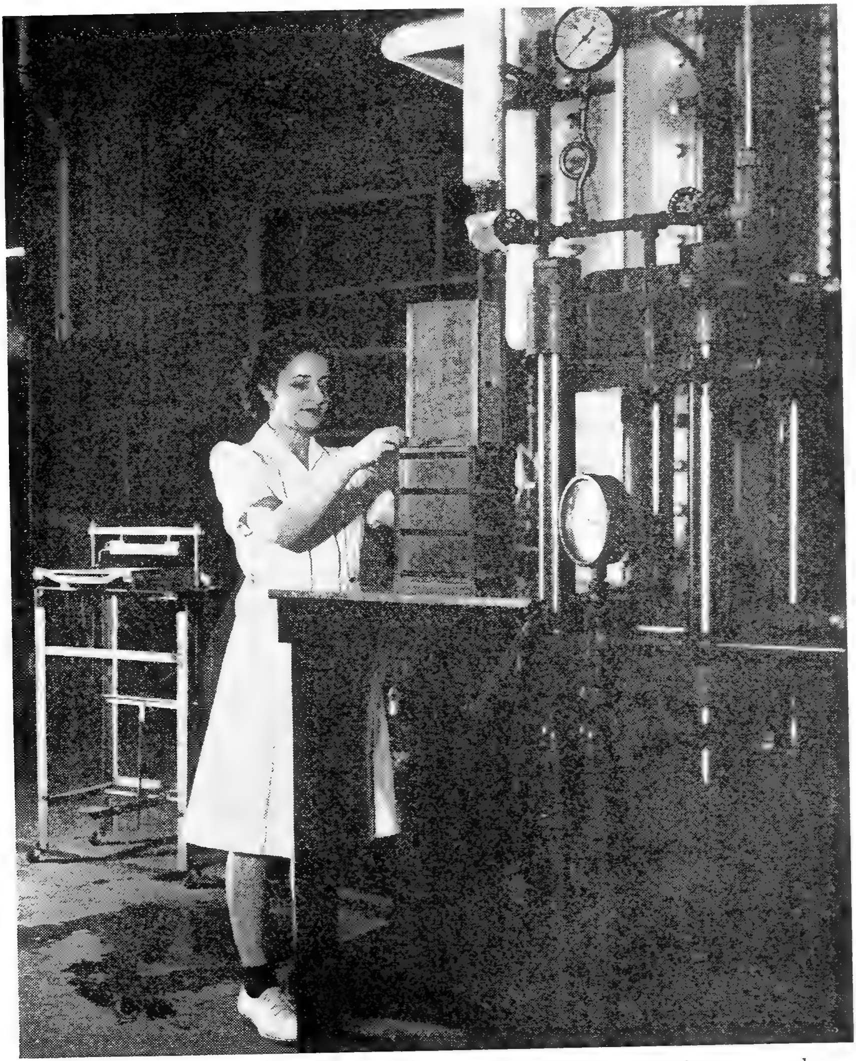

FIGURE 65.—Hydraulic press used in compression and packaging research on dehydrated foods at the Western Regional Research Laboratory, Albany, Calif.

by the plunger past the sides of the mold. Friction resulting from unpolished, inadequately lubricated steel surfaces diverts part of the pressure from the foodstuff to the sides of the mold; thus the effective pressure is decreased at the bottom of the mold, and poor cohesion and a laminated, leafy brick may result.

Sometimes very fine, dried materials or even powder are compressed. Examples are soup mixtures and dehydrated tomato-juice cocktail. Most dry powders flow readily and uniformly and such conditions are essential in the automatic feeding of presses. Dehydrated soup powders have been processed satisfactorily on industrial tablet-compressing machines. Dried tomato juice of 4 percent moisture content has been readily compressed hydraulically by 1,500 pounds per square inch at room temperature to a density of 60 pounds per cubic foot. The cakes were reconstituted to a 6.5 percent juice simply by beating with an egg beater and then adding boiling water and heating 1 minute. The dry compressed cakes crush easily.

Dehydrated vegetables of diced, sliced, stripped, or flake form yield high-density blocks that readily rehydrate and in which the content of fines is low. Hydraulic presses have been used in obtaining the results shown in table 13. The maximum pressure has been maintained for a period, or "dwell," of 1 minute. Blocking has been effected ordinarily at temperatures from 140° to 160° F. The purpose of an elevated temperature is to produce a pliable state of the vegetable for compression so that it will reach a high density without breaking into small pieces to any considerable extent. Firm blocks of somewhat lower densities have also been produced at ram speeds of 1 to 2 inches per second followed by a "dwell" of 15 seconds.

Fine material passing a 4-mesh screen, caused by compression under the conditions shown in the tabulation, did not exceed 5 percent of the rehydrated vegetables for any form of beets or carrots, or for onions or rutabagas. In general, the cohesion of the block was only fair at lower pressures and the same temperatures as those listed in the table. Higher pressures were not required for good cohesion nor were they necessary for adequate compression.

A slight expansion of blocks one-half inch thick occurs in that dimension when they are removed from the hot molds. This expansion is slight because these pieces cool rapidly. An estimate of

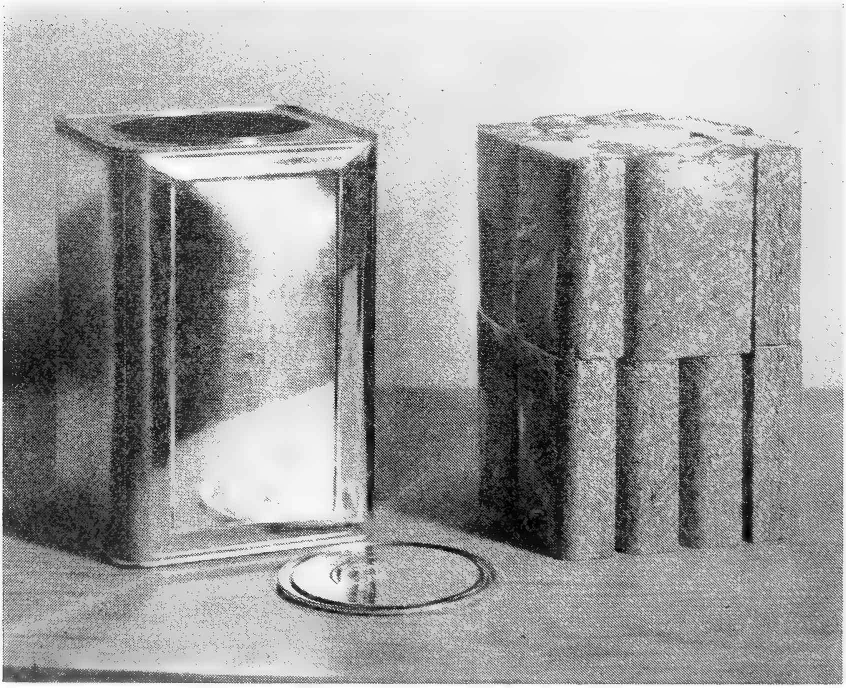

FIGURE 66.—Sixteen 2-pound bricks in arrangement shown at right fill a 5-gallon can with 800 servings of carrots.

the time required for cooling thick blocks of carrots in air is afforded by these test data: A block 2½ x 1⅜ x 6¾ inches of compressed, diced carrots cooled at the center from 140° to 90° F. in 3 hours, in air at 80°. The block was cellophane-wrapped, confined in a holding press, exposing the narrow sides and ends only. Removed at 90°, it held its shape.

Two-pound blocks of diced carrots were formed in a mold 6¹¹⁄₃₂ x 4⅜ inches of a suitable depth. The conditions were 160° F., 1,200 pounds per square inch, and a 30-second period at that pressure. The blocks were removed, wrapped in paper and cellophane, and sealed. After compression the dimensions over the wrapping were 6¹⁷⁄₃₂ x 4½ x 2³⁄₁₆ inches. The expansion in a direction perpendicular to the movement of the ram was ⁵⁄₃₂ inch on a 6½-inch length, with allowance for thicknesses of paper and cellophane. The immediate expansion parallel to the movement of the ram was three-eighths to one-half inch. An additional expansion resulted before it was stopped by the wrap and by air cooling. Holding presses prevent the latter expansion.

Actual practice will be a compromise between the goal of most desirable density, on the one hand, and, on the other, the obtainable equipment and its economic adaptation to use. A diagrammatic sketch of a packaging press is shown in figure 67.

Blocks should be wrapped and sealed at once in kraft paper or cellophane. If the packing case is large enough to permit slight swelling of the blocks, they may be packed immediately but if very close adherence to the dimensions of the mold is required, the blocks must be cooled under light pressure, part way to room temperature.

If compression is carried out with the wrapper inserted in the mold, complete cohesion of the block is not required. With this latter method of compression and wrapping, the wrapper must maintain its integrity as a moisture-vapor resistant sheet without tears, pinholes, or other breaks.

Holding Presses

The use of holding presses for the purpose of fixing the shape and dimensions of tobacco plugs and blocks of dried hops, catnip, and sage is well known. The time required for tobacco is 5 days; for hops, 12 hours. Such holding presses are not heavy or expensive, because little pressure is used. In one form a hardwood frame of rectangular shape is used. It has a solid bottom end and a loose top end. Plugs are stacked in it nearly to the top, the loaded frame is placed under a small screw press, the top pressed down, wedges are inserted above the top and against the top of the frame, and then the pressure is released and the loaded frame is removed. This type of press, with spaced blocks for ventilation, is one suggested way to cool under pressure.

SANITATION

A primary essential in a dehydrating plant that is endeavoring to make products of the highest quality is the maintenance of suitable standards of plant sanitation. Among the important factors affecting plant sanitation are building construction, equipment, access of rodents and other pests, storage facilities, water supply, waste disposal, and, most important of all perhaps, the operating personnel.

A plant should consist of well-constructed buildings with concrete floors capable of being satisfactorily cleaned, and free from crevices. The floors should be sloped to drains that are tightly joined to the sewerage system. All preparation and drying equipment that comes into direct contact with food should be washed thoroughly at frequent intervals. There are definite possibilities of a build-up of microorganisms, such as bacteria, molds, and yeasts, that may contaminate and even spoil the material that is put through such a piece of equipment. Stored raw material may contain fungus or bacterial

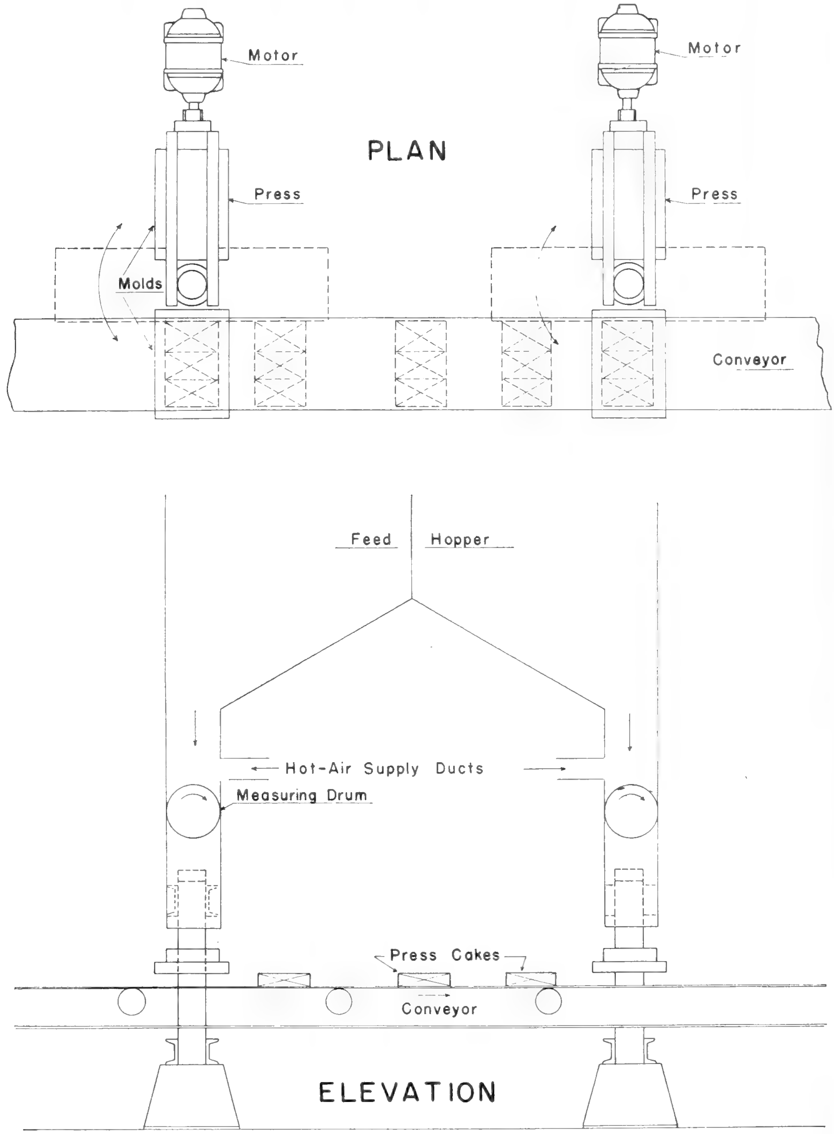

FIGURE 67.—Packaging press.

diseases which often spread rapidly. The storage bins or containers should be washed after the removal of each lot; otherwise infection will spread to other raw materials brought in later.

Water Supply

A most essential matter is a good water supply, which is both pure and abundant. It should be analyzed frequently because the character of water changes. Many times the waste from the plant itself contaminates the water supply. In general, hot water does a better cleaning job than cold water. The use of a steam hose can be very beneficial, but the steam must be applied under pressure directly to the area to be cleaned.

Detergents added to water are valuable in removing secretions of organic material from plant and equipment. Soap and cleaning compounds are excellent detergents. The efficiency of the cleaning operations may be enhanced by the use of chemical compounds containing chlorine. The use of a germicide alone without the cleansing operation is valueless, however. It should be associated with or immediately follow cleaning.

Waste Disposal

The selection of a dehydration plant site should include careful consideration of the waste-disposal problem. The capacity of the intended place of final disposal (creek, treatment plant, disposal bed, etc.) must be carefully evaluated. If the permissible loading is found to be less than that transported by the plant wastes, it will be necessary either to treat the wastes to lower their organic loading to the permissible value or else to move the plant to some other location where treatment will not be required.

The waste-disposal system is another matter of great importance, especially if an adequate municipal sewerage system is not available. Unless the wastes are properly conducted away from the plant, there is likelihood of pollution of the plant water supply, of odor nuisance, and even legal suits by property owners in the vicinity. Waste materials from vegetable-dehydration plants may be classified as "solid wastes" and "liquid or water-borne wastes." Solid wastes, such as trimmings, are in most cases readily disposed of as garbage, and do not enter into the liquid-waste disposal problem.

Liquid wastes from vegetable-dehydration plants are derived from the various washing operations. Most important are the wastes from the peeling units and the wastes resulting from washing the vegetables after they have been cut into small-sized cubes, bars, slices, or other shapes. Of lesser importance are the wastes derived from washing the raw product and the intermittent plant wash-up waters. Those liquid wastes are difficult to dispose of not only because of their volume, but also because of the large quantities of soluble and suspended organic matter which they transport. The organic material contained in the wastes from a potato-dehydration plant of 20 tons (unprepared basis) daily capacity, for example, may be roughly equivalent to that contained in the sewage flow from a town of 8,000 people. This organic matter will combine chemically with oxygen, when it is present, so that if the wastes are dumped into a small creek, drainage ditch, or other small body of water, the dissolved oxygen resources of that body of water will be quickly depleted.

When all the dissolved oxygen has been used up, the remaining (unoxidized) organic materials will begin to decompose anaerobically (ferment), and odoriferous and unsightly conditions will result. If the wastes are dumped into a sewer which flows into a sewage-treatment plant, trouble can again be expected. Most treatment plants are designed to handle only a limited loading of organic matter, and if this amount is exceeded the entire operating balance of the plant will be upset and objectionable conditions will exist. It is usually desirable to separate the dehydration plant-food wastes from toilet wastes. The relatively small volume of the latter can be treated separately by approved methods, which involve little difficulty.

If a dehydration plant is located in sandy terrain and there is sufficient area available, the waste water can be drained into the soil. It may be necessary to remove all suspended solids prior to the final disposal of the waste. This may be accomplished by first running the wastes from the plant through mechanical screens having a mesh of from 40 to 60 per inch. After this, the effluent is treated with a chemical agent which will change the pH of the product. Lime is one of the agents most commonly used for this purpose. By the addition of sufficient lime so that the pH is approximately 9.0, the waste material is rendered alkaline. Iron sulfate is another agent that can be used. These chemicals will facilitate the precipitation of finely suspended materials so that the waste water can be run into a settling tank, and the suspended solids removed by gravity. Even after such treatment, further treatment may be necessary when the relatively clear water is removed from the upper levels of the tank. This may involve the utilization of trickling filters or spray devices which permit an aeration of the wastes.

In some instances, the waste material can be run directly into shallow lagoons or closed areas of land diked on the edges, from which the liquids drain into the soil. The addition of small amounts of sodium nitrate has been found beneficial in controlling bacterial changes at this stage of waste treatment.

The best solution of the waste-disposal problem for any particular plant is a complicated one, and will generally require the services of a competent sanitary engineer. Careful consideration must be given to the possible means of final disposal, the degree of treatment required by each, and the funds available for building and operating treatment works. Possibly the most satisfactory scheme of disposal for general use is that comprising primary treatment by settling, with the effluent from the settling tank disposed of on irrigation beds, the liquid percolating into the ground. This scheme of disposal avoids any use of public sewerage systems and is therefore recommended whenever suitable irrigation beds are available.

Operating Personnel

No matter how good the plant, the equipment, and the water supply, if the employees have sanitary habits that are open to question, the products which they handle may be contaminated. If workers happen to have disease organisms on their hands, there will be disease organisms on the products.

Employees cannot be expected to keep clean unless proper facilities are available. Dirty wash rooms and dirty latrines, with no towels or soap, are not conducive to habits of cleanliness on the part of the employees. Some of the best food plants in the country have their washing facilities outside the rest rooms and the toilet room. The employees must wash their hands where they can be seen by the supervisor and the other employees in the plant. No one is permitted to go back to his work unless he has washed his hands in that place. Hot water, sanitary soap dispensers, and individual towels are provided.

CONTROL OF INSECTS AND MITES

Food manufacturing or processing plants, including dehydration plants, have the almost universal problem of insect and mite control. The most effective means of preventing the access of such pests to both the raw and finished materials is by the use of tight construction, ratproofing, screens, and thorough sanitation. Unceasing vigilance is necessary in removing the waste food materials upon which these pests thrive. There should be regular and thorough inspection of the premises and sampling of the products. Scalding water or vapor heat in the form or live steam will kill all forms of insect life on direct exposure.

Fumigation

A common method used in the control and extermination of insects and mites is fumigation. It can be used to treat suspected products, to check known infestations, and to clean out infestations and the premises housing them. It is especially suitable for areas that can be tightly enclosed. Fumigation is quick and effective and if properly handled leaves no complicating after effects. It should be done by trained or experienced personnel, with proper equipment, and at the right time and temperature. The chemical to be used is determined by the product and insects to be treated, and by the storage conditions under which the treatment is to be made. The absorption and adsorption of the gases by the infested materials must be considered. After treatment, the product must be properly aerated to allow the escape of contaminating gases.

Specially constructed, tight, ventilated fumigation rooms are extremely useful in treating sacked and packaged material. Steel vacuum fumigators are up-to-date devices for the treatment of insect-infested products. Some of these are large enough to enclose one or more freight boxcars at a single treatment. If possible, all fumigants should be applied from the exterior. Gas masks equipped with an unsaturated canister of proper type for the fumigant used should be worn when handling or applying toxic chemicals. All fumigants which are effective in killing insects are also toxic to humans. Some gases, such as hydrocyanic acid gas, methyl bromide, and others, are extremely dangerous and should be used only under expert supervision. The correct length of exposure varies with the concentration of the gas and the temperature. The temperature for the best results is usually 70° F. or higher.

Sprays

A spray composed chiefly of 10 to 15 percent oil emulsion, in which the viscosity of the oil is 90 or above, combined with an emulsifying agent, is of great value in disinfecting empty bins. Water-white kerosene alone or combined with oil extracts of pyrethrum or lethane is excellent also. These sprays may be applied by hand or power sprayers for small areas, or by regular orchard power sprayers for large and extensive structures. They should be applied to the ceilings, walls, floors, under the floors, and, in fact, everywhere insects or mites are likely to find hiding places.

The addition of 1 percent of creosote will kill the wood-boring cadelle and the lesser grain beetle in wooden containers. While there is no great fire hazard with the careful use of these sprays, proper precautions should be taken to prevent fires and to secure the sanction of insurance companies and underwriters involved.

Temperature and Moisture

Proper temperature and moisture control of storage facilities may effectively prevent infestation or retard the activities of insect pests indefinitely. Lack of such control may favor the insects and mites by providing ideal conditions for their development, feeding, and breeding in the foodstuffs.

Even and mild to warm temperatures combined with a high moisture content in the product (10 percent and above) will favor pest development by making the food more attractive to pests and the living conditions ideal. Thus, in the milder temperate regions and in the tropics, it is difficult to store dried fruits and vegetables because of the destructive work of mites, insects, fungi, and bacteria. Regions of great extremes of temperature offer a certain amount of protection to stored foods. Low temperatures and ordinary cold storage of 40° to 50° F. will prevent insect development in warehouses. Temperatures of 30° will kill all stages of the insect development if maintained constant throughout the bulk of the material.

High temperatures of 120° to 130° F. will prove effective in killing all forms of mite and insect life. The heat may be supplied by steam pipes and has proved effective where practical. Fans are invaluable in sterilization work.

The effectiveness of temperature is determined by the extent to which it is made to operate throughout the sacks, bins, or entire storage facilities. Unless the materials in storage are arranged so that temperature can penetrate evenly and effectively throughout the bins and sacks, it is necessary to provide proper ventilation or to bring the material into direct contact with the temperature. This will add considerably to the handling and shifting of the produce unless the material is stored in bulk in relatively small bins or units.

THE CONTROL LABORATORY

Every food-dehydration plant, large or small, must have a control laboratory. This laboratory may consist of minimum essentials, such as equipment and personnel for moisture testing, testing for adequate blanching, and testing of quality in raw and finished products, or it may be much more elaborate, even sufficient for research work.

Regardless of size, it is an important feature in any plant, and it should be regarded as a unit worthy of separate consideration and not as an incidental matter. The man or woman in charge should have chemical training and plant experience and should be free to devote as much time as possible to the work of the laboratory without too many additional duties.

Equipment is important. The laboratory should have well-lighted, roomy space, shut off from noises and odors. It should be free of dust, steam, and excessive vibration. Some of the necessary facilities and important items of equipment are work benches or tables, water, gas, electricity, and a sink. Although not essential, a refrigerator is very useful. Cupboard space for equipment, glassware, and supplies, and shelves for sample storage should be provided. Other items will be mentioned in subsequent discussions of the various types of tests and inspection work that are ordinarily carried on in plant-control laboratories.

Analysis, however carefully made, can do no more than give the composition of the sample. It is essential therefore that the sample be taken in such a manner that it will represent the lot under test. It must be remembered that variations in composition can be found in almost any lot of material. Portions of the material must be taken from various parts of the lot under test, carefully mixed, and either quartered by hand or, if the material is suitable, portioned with a riffle sampler. In this way a representative sample can be obtained. The remainer of the collected material can be returned to the lot.

After the sample has been collected it should be treated in such a manner that it will have the same composition when analyzed as when collected. Refrigeration can be used to hold samples for short periods of time. Samples to be analyzed for moisture must be kept tightly sealed until the analysis is made. Prompt analysis of samples after collection is always desirable and is almost a necessity when the sample is fresh material.

Examination of Raw Product

Since the quality of processed foods is greatly influenced by the stage of maturity of the commodity when harvested, canners and freezers give special attention to the maturity of raw products, and no less attention is required in dehydration. Other factors, such as color, uniformity, insect infestation, dirtiness, mechanical damage, and wilted condition are important and some attention has been directed toward the development of objective tests for evaluating some of these factors. Materials which would be rejected for canning or freezing are equally unacceptable for dehydration. Unfortunately few satisfactory tests for quality of the raw product have been devised and reliance must be based largely on general appearance as interpreted by an experienced operator. A few commonly employed tests are briefly described below.

TENDEROMETER TEST (PEAS)

One of the most recently developed methods for peas measures the force required to press a definite volume through a standard grid; the force necessary to shear the peas is directly proportional to toughness and inversely proportional to tenderness. The instrument used for this purpose is known as the tenderometer.

Procedure: The tenderometer value is determined for each load of shelled peas as it comes to the packing plant. Care must be taken to obtain a representative sample of the load. This is usually accomplished by filling a No. 10 can from lug boxes at several points. The peas are then cleaned and thoroughly mixed.

Before the tenderometer reading is taken it is desirable to bring the peas to a temperature of about 60° F. by immersion in water for 3 to 5 minutes. At least three readings should be taken, and the average used to represent the tenderness of the load. For first-grade peas the tenderometer value should probably not exceed 105; for second-grade, 115; and for third-grade, 125. It may be expected that third-grade peas will yield a very poor quality of dehydrated product.

COLOR TEST (GREEN LIMA BEANS)

The maturity of green lima beans is generally estimated by determining the percentage of white beans in a well-mixed, representative sample of the raw material.

Procedure: The sample should be obtained by subsampling various parts of each load. Usually each packer sets up his own percentage limits of white beans for different grades; however, it is generally required that first-grade green lima beans contain less than 10 percent of white beans.

PRESSURE TEST (SWEET CORN)

The maturity of sweet corn is usually determined by the thumbnail test and observation of the character of the expressed juice.

Procedure: The pressure required to break the hull of several kernels on several cobs selected from a representative sample is noted. At the stage of maturity desirable for dehydration the expressed juice is milk white in color and has a creamy consistency. If the juice is slightly cloudy the corn is too immature, and if it is thick and sticky the corn is overmature. Obviously this method is subject to considerable variation due to the personal factor.

MOISTURE CONTENT (SWEET CORN)

The maturity of sweet corn is sometimes estimated on the basis of moisture content in a representative sample. For dehydration, first-grade corn should have a moisture content of between 70 and 75 percent. Corn with a moisture content greater than this range will probably be too immature, and with a lower moisture content it may be too mature.

Procedure: Use the rapid distillation method (p. 146) on a carefully chosen sample obtained by careful removal of several kernels from several cobs selected from a representative sample.

Moisture Determination

Moisture content is probably the most important criterion of keeping quality of dehydrated products. A great deal of work has been done to develop accurate and reproducible methods, but the present status of the problem is far from satisfactory. Accurate determination of moisture requires painstaking and time-consuming procedures that are not practicable in control laboratories. It is therefore necessary to use methods which, though not measuring the absolute amount of moisture, give close approximations that are readily reproducible. The amount of moisture ordinarily determined is therefore an empirical quantity which will suffice for the purpose but must not be considered absolute.

Two general methods are used for the determination of moisture in vegetables. With the direct method the water is removed from the sample and determined from the loss in weight of the sample or by collecting and measuring its volume. This method is exemplified by the vacuum- and air-oven methods and by the so-called distillation (toluene) methods. The indirect methods do not require that water be removed but some other property of the material such as electrical conductivity, dielectric loss, or vapor pressure is used as a measure of moisture content. A vapor-pressure method has been described by Makower and Myers (*30a*).

VACUUM-OVEN METHOD

When applied to dehydrated products, the vacuum-oven method effects substantial completion of the drying process begun in the dehydrator. The sample of material is weighed before and after drying and the moisture content is calculated from the loss in weight. In actual practice the drying may not always be wholly completed in the time allotted to it because of the slow rate of removal of water. In some cases the loss in weight represents not only the loss of moisture but also loss of other volatile materials either present before or formed during the drying operation.

For those reasons the vacuum-oven method is empirical and the results obtained with it are reproducible only when the adopted procedure is strictly adhered to. The results are reproducible to within ±0.2 percent.

Equipment: Analytical balance, vacuum oven, vacuum pump, closed-type grinding equipment for dehydrated materials, such as a coffee mill, Waring or Universal blender or a Wiley mill, hand meat grinder for raw undried materials, one or more pyrex desiccators, a number of standard metal drying dishes with tight-fitting lids (diameter 2 to 3 inches, depth ¾ to 1 inch), and a 20-mesh sieve.

Procedure: The carefully selected sample of dehydrated material (25 gm. or more) is quickly transferred to the closed grinder and reduced to a powder which will pass readily through a 20-mesh sieve. From the well-mixed powder, duplicate samples of about 2 gm. each are accurately weighed into tared metal dishes which are promptly placed in the vacuum oven in direct contact with the metal shelf. With the lids "cocked" or removed the samples are dried for exactly 6 hours at 70° C. under a pressure held below 100 mm. of mercury. A stream of air, dried in a sulfuric acid tower (about 2 bubbles per second), is allowed to pass through the oven during the whole period of drying. After 6 hours the evacuation is stopped, the oven is brought to atmospheric pressure with dry air, the lids are put on the dishes in the oven, and the dishes are then transferred to desiccators charged with calcium chloride and are weighed after they have reached room temperature. The net weight is taken to be the weight of the moisture-free sample and the loss in weight as the moisture content of the sample.

Undried samples are handled in the same manner except that grinding is best carried out in a meat grinder, with care taken to avoid separation of expressed juice from the solids. Gentle but thorough stirring immediately before weighing to insure homogeneity of the sample is good practice.

Careful attention to the following factors will make it easier to obtain reproducible results:

Size of particles: Grinding the whole sample to pass a 20-mesh sieve favors reproducibility because small particles are more rapidly dried than large. Thorough mixing of the ground material before the samples are weighed is important, since the drier pieces of vegetable tend to break up into smaller particles than more moist pieces, and a separation into layers of coarser and finer particles may result in samples that vary considerably in moisture content. Most if not all fruits and vegetables dried to low moisture levels are very hygroscopic and must not be exposed to room air longer than is absolutely essential. Grinding must therefore be carried out quickly in a closed mill.

Temperature of drying: The temperature has been set at 70° C. At higher temperatures the drying will be more rapid but with some materials results will be erroneous because of decomposition and charring.

Air pressure: Drying in vacuum is more rapid than at atmospheric pressure and also protects the material from oxidation. However, in order to sweep out the moisture and to supply heat to the sample, some air is allowed to circulate through the oven. This air is first dried in the sulfuric acid towers to insure efficient removal of water from the samples.

Heat conduction: Metal dishes, preferably aluminum, are used to insure good heat transfer to the sample.

Time: The time has arbitrarily been set at 6 hours. Longer heating time will result in a greater loss of weight and in some cases as much as 50 hours may be necessary to obtain complete removal of water. However, at present the 6-hour period is used by Federal inspectors and therefore this period must be used in order to obtain comparable results. In research work on dehydrated materials it has been found desirable to heat for a longer time and for this purpose 16 hours is customarily used.

Other details: Weighing must be done on an analytical balance capable of determining the weight within 0.10 mg. Drying dishes must be handled with metal tongs to avoid inaccuracies in weights caused by oil or perspiration from the fingers. Any commercial type of vacuum oven can be used. Where difficulty is encountered in obtaining a vacuum oven, a satisfactory substitute in the form of a large pyrex vacuum desiccator placed in an ordinary air oven can be used. Still another way is to use a battery of Abderhalden-type driers made of glass, which are not subject to priority limitations. A temperature of 70° C. in the Abderhalden driers can be maintained by using in the boiling flask a mixture of carbon tetrachloride and chloroform (volume ratio 3.4 to 1). These liquids have the advantage of being noninflammable, but inhalation of the vapors should be avoided.

AIR OVEN METHOD

For air-oven analysis, samples are prepared in the same manner as for the vacuum-oven method and then heated in an ordinary air oven (unevacuated). The method has the advantage of simplified equipment, since no vacuum oven or pump is required. At temperatures near or above the boiling point of water, shorter time is required for a determination than by the standard vacuum-oven method. It is subject to larger errors, however, and must be checked against the vacuum-oven method for each type of material tested.

Procedure: The weighed samples are heated in the air oven for a period of time predetermined by comparison with vacuum-oven determination on the same material. Time of heating will depend on fineness of grinding and on the temperature. Dehydrated carrots ground in a coffee grinder (very fine grind) require about 2 hours at 100° C., 2½ hours at 90°, and 7 hours at 80°. Dehydrated potatoes ground similarly require about 1½ hours at 110°, 3 hours at 100°, and 6 hours at 90°. As in the vacuum-oven method the loss in weight is accepted as the water content of the sample. To obtain reproducible results, the time, temperature, and fineness of grind decided upon for each vegetable must be consistently adhered to.

DISTILLATION METHOD

By the distillation method the water is distilled out of the material at a temperature above the boiling point of water with the aid of an organic liquid immiscible with water, and the volume is read in a volumetric buret. The method is described in "Official and tentative methods of analysis," (*4*, p. 593). It can be used successfully only when calibrated against the vacuum-oven method because at the high temperatures used in the distillation, the vegetable material usually chars and the results are likely to be high and erratic. The method is more applicable to wet (20 to 90 percent water) than to dry vegetables.

Apparatus: Pyrex distilling flask (250 ml.) connected by means of distilling tube receiver to a 20-inch straight-tube Liebig condenser. The receiver is readily made by attaching the proper side tube to the calibrated section of a 5-ml. Mohr pipette.

Procedure: Approximately 75 ml. of toluene is placed in the distilling flask and to this is added the carefully weighed ground sample in an amount estimated to yield from 2 to 5 ml. of water. After the apparatus is connected, fill the receiving tube with toluene by pouring through top of condenser. Heat the flask at such a rate that about 2 drops of distillate per second is condensed. After most of the water has passed over, this rate is increased to 4 drops per second. When all the water appears to have been distilled, wash down the condenser with toluene and continue distillation briefly, repeating as necessary to remove final traces of water. Droplets of water adhering to the walls can be brushed down with a tube brush or with a piece of rubber attached to a copper wire and saturated with toluene. The whole operation should be completed within an hour and after the receiving tube has cooled to room temperature the volume of water collected is read. From this the percentage content of the sample can be calculated.

The apparatus must be kept clean with chromic acid cleaning solution and factors of particle size, volume of toluene, and heating time must be held close to the conditions used in calibration against the vacuum-oven method.

ELECTRICAL METHODS

With electrical methods an electrical property of the material is used as an index of the moisture content. Instruments are on the market, such as the Steinlite, Tag-Heppenstall, and the Moisture Register, that have been designed for use with grains and other materials and have recently been applied to dehydrated vegetables. These instruments must be calibrated for specific commodities against the vacuum-oven method. Moreover, because of a limited range they must be factory-adjusted for the range of moisture levels (such as 1 to 16 percent) over which they are to be used. For accurate work special calibrations are advisable for different varieties of the same commodity, and also for the same commodity subjected to different processing methods, such as time of blanching or temperature of dehydration. While the manufacturers claim an accuracy of 0.2 percent, the readings will probably show greater deviations as a result of variations mentioned above and also variations in temperature of the sample. Complete confidence can be placed in the measurements only when the unknown sample represents the same material and is ground and treated in the same manner as that used in preparing the calibration curve. In spite of shortcomings these instruments can be of great value in the plant by making it possible to follow the immediate progress of drying in test runs or in regular plant operations, since determinations can be made in about 5 minutes.

Determination of Adequacy of Blanching

Some changes that occur during blanching are solubilization of starch, denaturation of proteins, plasmolysis of the tissue cells, and destruction of enzymes. The relative importance of these changes in assuring that the ultimate consumer will receive the best-quality product is not known. However, it is now generally believed that most vegetables (onions excepted) must be adequately blanched in order to obtain a satisfactory product when subjected to present conditions of commercial dehydration and storage. The changes that occur during blanching depend on both the temperature that the commodity reaches and the time it is maintained at that temperature. It is hardly feasible for the processor to measure directly the internal temperature of the vegetable as it passes through his blancher. Therefore, in order to be sure that his blanching operation has been carried out properly, the processor must rely on a test that will indicate the extent to which the aforementioned changes have occurred. However, such a test can be of real value only to the extent that the change which it measures can be correlated with the stability and quality of the dehydrated commodity.

Because of the ease and rapidity with which enzymes can be detected, the relation between enzyme destruction and storage life has been studied extensively. It should be noted that the methods of testing for enzymes are empirical and that the degree of destruction corresponding to adequate blanching varies not only with the vegetables but probably also with the variety, maturity, and other factors. On the other hand, the amount of blanching (as measured by both time and temperature) required to obtain an adequately blanched product may likewise vary.

In spite of variations in results, enzyme tests are the chief means of estimating the amount of blanching treatment that dehydrated vegetables have received. With certain exceptions, dehydrated vegetables are tested for either catalase or peroxidase by Government procurement agencies. The selection of these enzymes was based chiefly on simplicity of test procedures, wide distribution of the enzymes in vegetables, and their sensitivity to heat. The procedures for the tests and the tolerances adopted during the early stages of the war were largely a matter of expediency; they represented an attempt to employ a safe margin of blanching even though adequate data on storage quality as related to blanching treatment were not available. Procedures are being modified continually in accordance with results of research.

Care is required in making the tests. Although the observations are generally subjective and qualitative, it is important to follow instructions carefully, since definite concentrations rather than excesses of reagents are used. For example, a two-fold variation in concentration of either hydrogen peroxide or guaiacol, as used in the early peroxidase tests, will cause a twofold variation in color obtained. Variations of several fold may occur unless (1) the hydrogen peroxide, which is very unstable in diluted solutions, is prepared fresh each day from full-strength concentrated reagent; (2) the amount of water used to cover the sample is controlled, and (3) the amounts of reagents added to the reaction mixture are properly measured. If the reaction mixture is excessively cold or warm, the results may vary as much as twofold. Also light, particularly sunlight, causes the color to fade, making it necessary to guard against excessive illumination.

A number of materials besides peroxidase has been reported to cause color formation in the peroxidase system. These include hemin, heavy metal salts, lignin, and others. The hemin and heavy metal salts ordinarily are not present in sufficient amounts to give a false positive test, and lignin, contrary to report, does not react with guaiacol either in the presence or absence of hydrogen peroxide. Benzidine, however, reacts with lignin to give a golden-yellow color, readily distinguishable from the blueblack formed in the oxidation of benzidine by peroxidase. The formation of the golden-yellow color is unaffected by hydrogen peroxide. The greater amount of blanching required to destroy the tendency of skins of corn and lima beans, and other specialized vegetable tissues, to color in the peroxidase test may be due to the nature of the peroxidase in these tissues or to the physical environment in which it occurs. Regardless of the explanation, it is unnecessary to blanch long enough to destroy the material responsible for this coloration. A positive test due to heat-stable contaminants such as the heavy metal salts can be detected by comparing the color intensity developed in tests run on boiled and unboiled samples.

Regeneration of peroxidase may be responsible for some of the variable results reported by the industry. In laboratory studies this phenomenon has not been observed in the dehydrated material but has been observed in blanched rutabagas, potatoes, cabbage, and others before dehydration. Frequently the inactivation of peroxidase during drying will exceed the regeneration, with the result that a lower activity will be obtained on dry material than on that freshly blanched. Drying conditions and time of holding between blancher and drier and between blancher and enzyme test will, however, affect results. It is important in comparing results on wet blanched samples with those on corresponding dried samples to make sure that the different results are not due to differences in test procedure. For example, allowance must be made for the water taken up during dehydration, or a considerable difference in final reagent concentration may exist. Also, as indicated above, the time of holding should be standardized to avoid variable amounts of regeneration.

The test that the processor uses at the end of his blancher may vary not only with the vegetable but also with the consumer or purchaser. Vegetables to be purchased by Government agencies should be tested at the end of the blancher by a procedure that will correlate with the inspection test on the dried material. The tolerance permissible at the blancher can best be determined by the plant chemist, since the regeneration and inactivation that occur during drying will vary with plant practice. When possible, the product should, of course, be blanched appreciably more than the minimum. On material prepared for the general public it may be desirable to use a different blanching treatment and hence an enzyme test having a different tolerance, since a wide margin of safety has been required on vegetables dehydrated for the armed forces because of the severe storage and transportation conditions that they may encounter.

In general the catalase test is not recommended, because catalase is too easily destroyed in most vegetables and would therefore indicate only gross underblanching. Complete and permanent destruction of peroxidase, on the other hand, would correspond to overblanching of many vegetables. The use of peroxidase in these cases therefore requires a tolerance. Although the peroxidase test is not entirely satisfactory because of the many factors that affect it, the following procedure is presented for illustrative purposes and will doubtless be improved or replaced as research proceeds.

The procedure employs guaiacol, one of the most suitable peroxidase substrates, and higher concentrations of reagents to avoid the effect of small variations in reagent concentration. Further, it can be made essentially objective by the use of color standards. Use of color standards permits the adoption of tolerances that can be varied to suit any particular purpose. Processors must, of course. use the current test that the product must pass.

PEROXIDASE TESTS

Peroxidase catalyses the oxidation by hydrogen peroxide (or certain other peroxides) of a number of compounds such as pyrogallol, guaiacol, benzidine, catechol, etc. to give colored compounds. Most of the procedures for estimating peroxidase are based on the observation of the color formed after various periods of time.

The following procedure depends on the observation of guaiacol oxidation product color in solution and disregards the color of the solid pieces. This procedure has been used experimentally on white potatoes and may require some change in regard to observation time, size of sample, or other factors if used on other vegetables.

Reagents: Use A. C. S., U. S. P., N. F., or equivalent grade chemicals: 10 percent guaiacol in 95 percent alcohol. 30 percent hydrogen peroxide. 5M ammonium acetate (193 gm. of $(NH_4)C_2H_3O_2$ dissolved in sufficient water to make 500 ml. of solution).

Procedure: The test should be made in triplicate. To each 25-gm. portion in a 400 ml. beaker add 5 ml. of 5M ammonium acetate and 270 ml. of distilled water. Stir thoroughly with a stirring rod, without breaking pieces, and allow to rehydrate for one hour. After the hour of rehydration add 5 ml. of 10 percent guaiacol, stir, and add 3 drops (0.15 ml.) of 30 percent hydrogen peroxide (equivalent amounts of each concentrations may be used). Again stir thoroughly and allow to react for just one hour without agitation. After the addition of the hydrogen peroxide the samples must be protected from direct sunlight and shielded from intense artificial illumination. (Covering with a towel is a convenient method of protecting samples from light.) At the end of the hour of reaction time stir thoroughly, filter a portion of the sample through fairly fast paper into a test tube (18 x 150 mm.) and compare the color of the filtrate with a color standard or determine the extent of coloration with a colorimeter.

A stable color standard may be made from $Co(NO_3)_2.6H_2O$ and $K_2Cr_2O_7$. For freshly dehydrated white potatoes that are to be used domestically the color in the filtrate should be less than that of a standard containing 0.01 percent $K_2Cr_2O_7$ and 0.65 percent $Co(NO_3)_2.6H_2O$. If the potatoes are not seriously damaged by additional blanching it would be consistent with the principle of the safest practical margin to use a standard having one-half or one-third the above concentrations of salts. As mentioned before, the test procedure used at the end of the blancher would need to be correlated in the plant with the test to be used on the dehydrated material.

Vitamin Determinations

The principal vitamins contained in dehydrated fruits and vegetables are ascorbic acid (vitamin C), carotene (provitamin A), and certain members of the B group, such as thiamine and riboflavin. Of these the B vitamins are comparatively stable and, though suffering some loss in dehydration, are retained well in storage. Thiamine and riboflavin occur in many vegetables but are present in noteworthy amounts principally in the greens and legumes.

Ascorbic acid occurs widely in citrus fruits, berries, tomatoes, cabbage, greens, carrots, potatoes, and others, but it is difficult to preserve and frequently undergoes destruction to the extent of 50 to 75 percent in the course of processing. Retention in storage is aided by low moisture content, low oxygen content of storage atmosphere, and low storage temperatures. Adequate blanching and rapid drying also favor its retention during dehydration and storage, although substantial losses may be encountered in the blanching operation. With ultrarapid drying, such as spray drying, retention of as high as 90 percent can be attained without difficulty. Ascorbic acid is of considerable importance in dehydrated foods and it is most desirable to retain as much of the original content in the fruits and vegetables as possible. Because of its sensitivity to conditions that also tend to affect flavor characteristics adversely, measurement of its retention has been suggested as a means of following objectively general quality retention.

Vitamin A does not occur in plant materials, but its precursor, carotene, does occur in green and yellow vegetables,[13] notably greens, carrots, and sweetpotatoes. Like ascorbic acid it is labile and somewhat difficult to retain through the various steps of processing and storage. However, it appears to be affected only slightly by the moisture content of the dehydrated product but to a large extent by the oxygen content of the storage atmosphere, especially during storage at high temperatures. For this reason inert gases, such as nitrogen and carbon dioxide, are employed in packaging carrots in hermetically sealed containers. Because it contributes largely to the color of some vegetables, its destruction is closely related to adverse changes in their characteristic color. Moreover, in carrots it appears to undergo transformation to beta-ionone, an organic compound with a pronounced violet odor.

Vitamin assays are much more complicated than moisture or enzyme determinations and require special equipment and more highly trained personnel. Because of limited space it is impossible to present complete details of the methods but general instructions and precautions for application of certain accepted procedures to dehydrated foods are given below. References to more comprehensive discussions are cited and it is strongly urged that the chemist or laboratory technician refer to them before undertaking the performance of these assays if he wishes to attain that high degree of accuracy in his results that comes with a full understanding of the procedures. Bioassay will not be considered since it requires specialized training and experience, animal colonies, and long periods of time. Moreover, for thiamine, riboflavin, ascorbic acid, and carotene, quite reliable chemical methods are now known that make possible large numbers of determinations in a short time.

CAROTENE

The analysis for carotene as here outlined takes into account the problems involved in the quantitative extraction of carotene from dehydrated vegetables. The procedure also employs a chromatographic adsorption step similar to that now being investigated by the committee on the determination of chlorophyll and carotene of the Association of Official Agricultural Chemists. The precision of the method has been studied and in the case of dried carrots and spinach the standard deviation has been found to be less than ± 4 percent of the mean carotene value.

Equipment: Colorimeter (reliable make) with blue filter, Waring blender or equivalent, hand-operated meat grinder, funnels (5.5 cm. Büchner, sintered-glass 500-ml. separatory), flasks (500- and 100-ml. volumetric, 50-ml. round bottom), calcium phosphate chromatographic column.

Reagents: Acetone (90-percent), diethyl ether, petroleum ether, Filter-Cel, pure crystalline carotene, calcium phosphate ($CaHPO_4$).

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[13] In the analysis of sweet corn, cryptoxanthin as well as carotene contributes to the vitamin A value and special treatment is required.

Procedure: Five grams of finely divided sample material is weighed, placed upon a Büchner funnel and washed with warm water (50° C.) under gravity flow (about 200 ml. total). The filter paper and the softened washed sample are transferred quantitatively to a blender and disintegrated in the presence of 200 ml. of 90-percent acetone.[14] Five grams of Filter-Cel is added during the last 30 seconds of desintegration and the suspension is filtered under reduced pressure directly into a 500-ml. volumetric flask through a sintered-glass funnel. The cake formed upon the filter by means of a tamper and the application of vacuum is successively washed with a 50-ml. portion of 90 percent acetone, resuspended in an equal portion of acetone, reformed, washed, resuspended, etc., until the residue and filtrate are colorless. The filtrate is then made to volume (500 ml.) with 90-percent acetone.

In the analysis of fresh samples, 25 gm. of thinly sliced plant material (50 gm. if weakly pigmented) is disintegrated in a blender in the presence of 200 ml. of 90-percent acetone.[15] Subsequent steps are identical with those given above for dehydrated materials.

A 100-ml. aliquot of the 90-percent acetone extract is mixed with 75 ml. of diethyl ether in a 500-ml. separatory funnel and the acetone removed by the continuous washing method of Hubert (*22*) and LeRosen (*26*). In this method water is continuously introduced below the ether layer in the separatory funnel through a glass tube bent upward at the end. The tube is held in a rubber stopper which closes the upper opening of the funnel. The stream of water introduced through the tube and emitted from the lower stopcock washes the acetone from the ether hyperphase. Traces of water remaining in the hyperphase are forced out with the addition of 20 ml. of petroleum ether and the water drawn off through the lower stopcock.

The hyperphase is then made to volume in a 100-ml. volumetric flask with petroleum ether. Triplicate 25-ml. aliquots of this solution are placed in 50-ml. round-bottom flasks, and the solvents are evaporated off under reduced pressure with a small stream of nitrogen in a constant-temperature bath held at 40° C. Each of these samples is redissolved in a few cubic centimeters of petroleum ether and transferred quantitatively to a calcium phosphate ($CaHPO_4$) chromatographic column as described by Moore (*32*). Carotene is washed through the column with petroleum ether and caught in a 100-ml. volumetric flask. Other pigments are retained on the column.

After dilution to volume, the carotene is determined spectrophotometrically by the use of wave length 436 μ ($\alpha = 199$) as suggested by Beadle and Zscheile (*6*) or colorimetrically with the use of a blue filter. In the latter method, the colorimeter can be calibrated by the use of solutions of known concentration of pure crystalline beta-carotene dissolved in petroleum ether.

ASCORBIC ACID

The following procedure for the determination of ascorbic acid (*27*) has been found particularly useful in handling fresh, frozen, and dehydrated food materials.

Apparatus: Photoelectric colorimeter of the direct-reading type with a filter in the 520-millimicron range, blender, calibrated pipettes of 1-ml. and 9-ml. capacities.

Reagents: Metaphosphoric acid, 1 percent (freshly prepared); indophenol dye solution, approximately 13 mg. per liter. If metaphosphoric acid is unavailable, oxalic acid (0.25 percent) can be substituted, provided the extracts are tested promptly.

Procedure: Blend 25 to 50 gm. of fresh fruit or vegetable tissue with 500 ml. of 1-percent metaphosphoric acid in a blending machine operated for 5 minutes at high speed. If the material is of high ascorbic acid content, such as leafy vegetables, raspberries, strawberries, or asparagus, use the smaller quantity. Fifty grams is used with foods containing less ascorbic acid, such as potatoes, carrots, peaches, plums, and apricots. If a dehydrated fruit or vegetable is

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[14] This washing process is unnecessary for many dehydrated vegetables, such as carrots, spinach, chard, and others. In these cases 25 ml. of hot water (50° C.) is added to the 5-gm. sample in the weighing bottle and allowed to stand 1 hour. The sample and excess water are then transferred quantitatively to a blender with 175 ml. of acetone, and the sample is disintegrated and extracted as described.

[15] Some difficulty has been experienced in obtaining complete extraction of raw carrots by the procedure described. Steam blanching for 2 to 5 minutes prior to disintegration has been found to facilitate the extraction. Since carotene is stable in steam blanching of this duration, the inclusion of this step is recommended with raw carrots.

being analyzed, 5 to 10 gm. of sample is sufficient, in accordance with this same classification. These may require a half hour of soaking in the acid before blending.

Centrifuge or filter the extract through fluted filter paper. Moderate turbidities do not interfere, since the instrument is calibrated with proper blanks. Extracts of starchy vegetables, such as potatoes, should be centrifuged or suction-filtered, if difficulty is encountered with the ordinary filter.

Pipette 1-ml. portions of the filtrate into three matched tubes from the photoelectric colorimeter. Add 9 ml. of distilled water to one tube and adjust the colorimeter to read 100 with this tube.

To each of the other tubes add 9 ml. of a previously standardized indophenol dye solution from a calibrated rapid-delivery pipette. Take a reading in the colorimeter 15 seconds after the beginning of the addition of dye. This reading is G_2, from which the corresponding L_2 value is obtained from the calibration table provided with the instrument or calculated from the following formula: $L=2-\log G$ or $\log 1/T$.

Ascorbic acid, mg. per 100 ml. of filtrate$=K\ (L_1-L_2)$.

K must be determined for each colorimeter by preparation of a curve with pure ascorbic acid.

$K=C/D$.

C=concentration of ascorbic acid in mg. per 100 ml.

D=density$=(L_1-L_2)$.

The equation for fruit and vegetable tissue becomes:

Ascorbic acid, mg. per 100 gm. tissue=

$$K\ (L_1-L_2)\frac{\text{ml. acid extractant+ml. water in sample}}{\text{gm. of sample}}$$

With dehydrated vegetables, the moisture content (if below 5 percent) can usually be neglected. The formula then becomes:

$$\text{Ascorbic acid, mg. per 100 gm. product}=K\ (L_1-L_2)\frac{\text{ml. acid added}}{\text{gm. sample}}$$

Add the dye to the tube outside the colorimeter and agitate the tube slightly before putting it into the instrument. If an automatic 9-ml. pipette is used, it must extend to near the surface of the liquid in the tube to avoid splashing and must be calibrated to drain uniformly in less than 5 seconds.

The dye is standardized by noting the 15-second reading given by a tube containing 1 ml. of 1-percent metaphosphoric acid and 9 ml. of the dye solution. This value is G_1, from which L_1 is obtained on the calibration table or from the formula above. This standardization is very much easier and faster than titrimetric procedures.

THIAMINE AND RIBOFLAVIN

Because of the relatively infrequent determination of thiamine and riboflavin in dehydrated fruits and vegetables, details are not presented here. It has been found that the method of Conner and Straub (*12*) is useful for both fresh and dehydrated products. This is a fluorometric method in which the vitamins are extracted by dilute acid and separated from one another by adsorption procedures.

Determination of Sugar (Vegetables)

Determination of sugar content is valuable in examinations of raw products for maturity or loss of quality in storage. It is often used on dehydrated products, such as carrots, sweet corn, and potatoes, to indicate quality, loss of solubles in blanching and washing, and causes of difficulty in drying, and also to obtain information useful in the compression of the dried materials. The method described here[16]

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[16] Essentially as developed by J. P. Nielsen of the Western Regional Research Laboratory by modification of the method of W. Z. Hassid (*19, 20*).

has been found rapid and very satisfactory for both fresh and dehydrated products.

Apparatus: Blender, analytical balance, volumetric flasks (50 ml.), burette (10 ml.).

Reagents: Ethyl alcohol, saturated solution of neutral lead acetate, saturated solution of disodium phosphate, dilute hydrochloric acid (mix 100 ml. concentrated HCl with 1,100 ml. water), sodium hydroxide solution (24 gm. NaOH made to 100 ml. of solution with distilled water), alkaline potassium ferricyanide solution (8.75 gm. $K_3Fe(CN)_6$ plus 10.6 gm. anhydrous sodium carbonate made to 1,000 ml. with distilled water and stored in refrigerator), sulfuric acid solution (5 N), standardized ceric sulfate solution (0.01 N), phenolphthalein (0.1 percent in 90-percent alcohol), Setopalin C indicator (0.1 percent in water), Mohr's salt solution (0.01 N), dextrose solution (1 percent in 0.25-percent aqueous benzoic acid).

Procedure: Before the test is applied dehydrated materials must be rehydrated by heating in distilled water at 50° to 60° C. for 2 hours. An amount of dehydrated material corresponding to 60 gm. of fresh carrots, 75 gm. of fresh corn, or 150 gm. of fresh potatoes (or approximately equivalent amounts of other products, based on their estimated sugar content) is added to 150 ml. of water plus an additional amount calculated to bring the dehydrated material to the fresh basis. With fresh products only the 150 ml. of water is added. The mixture, fresh or rehydrated, is thoroughly broken up by agitation for 2 to 4 minutes in a blender. A 15-gm. portion of the resultant suspension (keep well mixed to maintain uniformity) is transferred to a 50-ml. volumetric flask with a minimum amount of ethyl alcohol. Add 2 ml. of a saturated solution of neutral lead acetate, mix, and add 4 ml. of a saturated solution of disodium phosphate. Make up to volume by addition of water and alcohol in such proportion as to yield a final mixture of about 50-percent alcohol. Mix thoroughly and filter through a folded filter paper.

For total sugars, transfer 5 ml. of filtrate to a 50-ml. volumetric flask. Add 10 ml. of the dilute hydrochloric acid. The sample can then, according to convenience, be heated in a boiling-water bath for 10 minutes, cooled, made up to 50 ml. with distilled water, and mixed; or it can be allowed to stand 24 hours at room temperature (approximately 25° C.), made to mark with distilled water, and mixed.

Transfer 5 ml. of the solution to a 22 x 175-mm. test tube; add 1 drop of phenolphthalein and the NaOH solution until the pink color develops. Add HCl until pink color disappears. Use a dropping tube for additions of NaOH and HCl, as only a few drops of each are required.

Add 10 ml. of the alkaline potassium ferricyanide solution and heat in a boiling-water bath 15 minutes. Cool and then add 8 ml. of 5N H_2SO_4. Add 7 to 10 drops of Setopalin C indicator and titrate with ceric sulfate solution from a 10-ml. burette. The end point is indicated by the sharp change from greenish yellow to golden brown.

Ceric sulfate may be standardized against 0.01 N solution of Mohr's salt. An exact dextrose equivalent can be obtained with 5-ml. aliquots of dilute dextrose solution made up from the 1 percent stock solution by dilution so that 5 ml. contains 2.5 mg. of dextrose. It is advisable to standardize the ceric sulfate with the dextrose solution at least once a month. If it is more convenient, pure sodium oxalate may be used for the standardization instead of dextrose. In this instance the equivalent weight of invert sugar is 33.8 gm. and of sucrose 32.1 gm.

It is usually advisable to run titrations in duplicate and to take the average. Generally the agreement is within 0.05 ml. of the ceric sulfate. A blank run should be made on alcohol and the reagents added as in a regular determination. This value, usually 0.1 to 0.2 ml. of ceric sulfate, is subtracted from the values for the samples to obtain true values. By means of the dextrose value of the ceric sulfate as found by titration of pure dextrose, and the amount of aliquot as run, the percentage of sugar, expressed as dextrose, is readily found. The aliquots titrated should not have more than about 7.0 mg. of dextrose.

Determination of Starch (Vegetables)

Starch determinations are often useful in evaluating the quality and maturity of starchy vegetables and may be valuable in considering their drying characteristics. Nielsen's method (*37*) has proved rapid and useful and is described as follows:

Apparatus: Photoelectric colorimeter with test-tube adapter, a dozen or more matched test tubes, red filter, blender, balance (analytical or torsion sensitive to 0.01 gm.), air oven.

Reagents: Perchloric acid (2.7 parts by volume of 72 percent reagent-grade solution plus 1 part water), sodium hydroxide (2 N), acetic acid (2 N), potassium iodide solution (10 percent), potassium iodate (0.01 N), sodium thiosulfate (0.1 N), ethyl alcohol, ether, phenolphthalein (0.1 percent in 90 percent alcohol).

Procedure: A 100- to 200-gm. sample of the fresh, frozen, or canned vegetable (or equivalent amount of dehydrated material rehydrated by heating one-half hour or longer in an amount of water necessary to give the 100-gm. sample) is placed in the disintegrator cup with an equal weight of water, and the instrument is allowed to run at high speed for 3 to 4 minutes. Two or 3 grams of the ground sample, depending upon starch content, is weighed directly into a 30-ml. beaker on a torsion balance. One ml. of water (or none if 3 gm. was taken) is added, and then exactly 3.7 ml. of perchloric acid, prepared as directed above, is slowly added with thorough stirring with a glass rod, so that there will not be momentary high concentrations of the acid in any portion of the sample. The mixture is allowed to stand with occasional stirring for about 10 minutes. If the product is not viscous, the simplest method of stirring is to whirl the contents of the beaker during the addition of the acid as well as in the later stirrings.

After standing, the mixture is made up to 25, 50, or 100 ml. with distilled water, depending upon starch content, and then poured into a suitable test tube to settle. A 1-ml. aliquot of the supernatant liquid is pipetted into a 100-ml. beaker and 6 ml. water added. A drop of phenolphthalein is added and the solution is brought to a pink color with a few drops of 2 N sodium hydroxide. Now 2.5 ml. of 2 N acetic acid, 0.5 ml. of 10 percent potassium iodide, and 5 ml. of 0.01 N potassium iodate are added accurately, and the solution is allowed to stand at least 10 minutes with occasional stirring. Dilute to 25, 50, or 100 ml., depending upon starch content. The color is estimated in a photoelectric colorimeter with a red filter having a transmission range from 640 to 700 millimicrons. The colorimeter should be set at zero absorption or the readings corrected with a blank containing all of the reagents. If the filtrate used in developing the starch-iodine color is turbid, an extra blank reading should be made if precise results are desired. This can be done by discharging the blue color with a few drops of 0.1 N sodium thiosulfate and comparing the turbid solution against the first blank with its iodine color discharged by thiosulfate.

The percentage of starch is calculated from a curve prepared from the colorimeter readings of a known range of starch concentration. For solution depths of about one-half inch, the best range of starch concentrations is from 0 to 3 mg. per 50 ml., preferably 1 mg.

Soluble starch cannot be used for standardization. If accurate results are desired, starch prepared from raw unblanched material similar to that which is to be analyzed should be used. Equal weights of starch from different products, such as potatoes and peas, do not give the same amount of color with iodine; therefore one type of starch cannot be used as a standard for all products.

Since factors have now been established among the various starches, a single standard, such as potato starch, suffices. If a series of analyses are to be carried out on a given product and only relative results are desired, then potato starch, which is easily prepared, can be used to prepare a standard curve.

Disintegrate the raw product in the mixer with an equal weight of water. Separate out the fibrous material by washing the ground pulp through a 60-mesh screen. Now place the material that passed through the screen in a large beaker or pan and stir with a large volume of water. Allow the starch to settle and decant off the water. Repeat this process until the starch is free of extraneous material. Now wash the starch with alcohol and ether and dry in an oven at 70° to 80° C. for 30 minutes. This should give a starch that is reasonably pure. Analyses can be made to establish its purity if such accuracy is desired.

Note: If approximately half of the water is added to the sample in the blender and the instrument run at low speed controlled with a rheostat until the sample is well disintegrated, and then the remainder of the water is added and the blender gradually run faster until maximum speed is reached, a more nearly homogeneous product is obtained. The volumes of the first and second dilutions depend upon the starch content of product and the internal diameter of the colorimeter tubes.

Determination of Sulfur (Dried Fruits and Vegetables)

It is now common practice to treat cabbage with a solution of sodium sulfite or a mixture of the normal sulfite and bisulfite prior to dehydration. Future specifications may provide for similar treatment of other vegetables (carrots, potatoes, and possibly others) with sulfite solutions and control of this operation involves the determination of the sulfite in the dehydrated products. Dried and dehydrated fruits are commonly exposed to sulfur-dioxide gas in sulfuring chambers before sun-drying or dehydration. The Monier-Williams procedure (*4*, pp. 463-465) can be used satisfactorily for both sulfured fruits and vegetables. It is a distillation method and is time-consuming and not especially well adapted to field work where a minimum of equipment is desired. Recently a direct titration method has been devised by Prater and others (*39a*) especially for use on dehydrated foods. The method as applied to dehydrated cabbage follows. Little modification is necessary for other vegetables or fruits but reference to the discussion in the paper by Prater and others (*39a*) is desirable before undertaking the assay of such materials.

Apparatus: Blender, analytical balance, burette (50 ml.), flasks (1-liter Erlenmeyer), graduated pipettes (10 ml.).

Reagents: Sodium hydroxide (5 N), hydrochloric acid (5 N), acetone, starch solution (1 percent soluble), iodine solution (0.05 N).

Procedure: The shredded sample should be ground dry in the blender immediately before the test is begun. From the ground material two 8-gm. samples are weighed (to 10 mg.) and labeled *A* and *B*. Each sample is transferred to a 1-liter flask and 400 ml. of water and 5 ml. of 5 N sodium hydroxide added. The mixtures are allowed to stand for 20 minutes with occasional shaking. Each is acidified with 7.5 ml. of 5 N hydrochloric acid, which should reduce the solution to a pH of about 2.0. To sample *B*, 40 ml. of acetone is immediately added and the mixture let stand for 10 minutes. To sample *A*, 10 ml. of 1-percent soluble starch solution is added and the sample titrated to the starch end point with 0.05 N iodine solution. After the required 10 minutes, sample *B* is titrated in the same manner.

In order to obtain the blank values for the reagents, titrations *A* and *B* are repeated without the cabbage and the respective blanks subtracted from the first titrations for *A* and *B*. Blank determinations need be run only once a day or when fresh solutions are employed. The sulfur dioxide in parts per million is obtained by multiplying the corrected titration for *A*, minus that for *B*, by 200.

The inexperienced analyst will find it desirable to run a preliminary titration, adding the iodine rapidly, about 0.5 to 1.0 ml. at a time to determine the approximate end point. In titration *A*, with a titer of 4 to 15 ml., a double end point may be observed, the first where the whole solution becomes blue but fades rapidly. The second is permanent for several minutes, and is obtained on addition of 0.5 to 1 ml. more iodine solution. A double end point is also observed with sample *B*, but both are much less permanent, owing to slow liberation of SO_2 from the acetone. It is recommended that in each case the first or flash end point be taken. Titration *A* yields total SO_2, both free and bound, and other reducing substances. Titration *B* yields only the other reducing substances, because a complex is formed by the acetone and SO_2 which does not immediately react with the iodine, but only gradually, and on standing. The acetone concentration must be controlled, because an unsatisfactory end point is obtained if it is too high. The acetone complex is unstable, and the titration must be conducted in the range of pH 1.8 to 2.6, where, in these cabbage tests, the complex shows greatest stability. Therefore both the 5 N NaOH and the 5 N HCl should be added by pipettes rather than from graduated cylinders.

Analysis of Atmosphere in Cans of Dehydrated Vegetables

In plants where dehydrated vegetables are gas-packed in accordance with purchasing specifications, a method of analyzing the atmosphere of the packed cans is useful. Figure 68 shows a gas-sampling assembly, a can-puncturing device, and an Orsat gas-analysis apparatus.

The base of the gas-sampling assembly is a steel plate 12 x 12 x ½ inches. Two metal rods of ½-inch diameter (*B*) are screwed into the base. A wooden base of hardwood can be substituted, with lock nuts on the rods to fasten them firmly to the base. The metal rod (*C*), which carries the puncturing device, is held in position by the clamp holders (*D*) and can be raised or lowered to any suitable height.

The can-puncturing device consists of a threaded tee (*E*), which supplies the force required to puncture the can, and the puncturing device proper, (*F*). These are also shown in detail. Glass capillary tubing (2-mm. bore) connects the can-puncturing device to a gas-sampling tube (*G*) of approximately 300-cc. capacity. This tube is connected by rubber tubing to a leveling bulb (*H*) containing mercury. All necessary stopcocks are shown in the diagram. As a substitute for mercury, a solution made up in the ratio of 10 gm. of anhydrous sodium sulfate, 40 gm. of water, and 2 cc. of sulfuric acid, with the addition of some methyl orange indicator can be used.

Figure 68 also shows (upper left) a portable Orsat gas-analysis apparatus, consisting of a gas burette (*A*) enclosed in a water jacket (*B*), absorption pipettes (*C* and *D*) for carbon dioxide and oxygen, respectively, and a leveling bottle (*E*) filled with a confining liquid of the same composition described above as a substitute for mercury. All necessary stopcocks are shown, and the apparatus is enclosed in a wooden case (*F*). Other types of gas-analysis apparatus are also suitable.

A commonly used stock solution for the preparation of absorbents for carbon dioxide and oxygen consists of 800 gm. of potassium hydroxide per 1,000 cc. of solution. For carbon dioxide, the stock solution is diluted with water in the ratio of 100 cc. of stock to 60 cc. of water. Ordinarily the absorption pipettes have a capacity of 160 to 180 cc. of solution. To make up the alkaline pyrogallol solution for oxygen determinations, ascertain how much solution will be required to fill one leg of the pipette and about a quarter of the other leg. In the oxygen absorption pipette (*D*), allow for the use of a half-inch layer of mineral oil (U. S. P.) to be used on the surface of the open side of the pipette. Now add the calculated amount of caustic potash solution from stock to the open side of the pipette. On top of that solution add a half-inch layer of the oil. The pyrogallol required is in the ratio of 15 gm. of pyrogallol to 100 cc. of stock caustic solution. Dissolve the pyrogallol in two-thirds of its weight of hot water, place a long-stemmed funnel in the pipette with the tip below the layer of oil, and run the pyrogallol solution into the caustic. The oil prevents rapid oxidation of the alkaline pyrogallol solution, by contact with air. This protecting device is used in place of the rubber balloons commonly used in the past for this purpose.

The process of sampling is carried out as follows: A can is placed in the stand, lid uppermost. The bulb (*G*) is filled with fluid to the cock nearest the puncturing device, and all three stopcocks are closed.

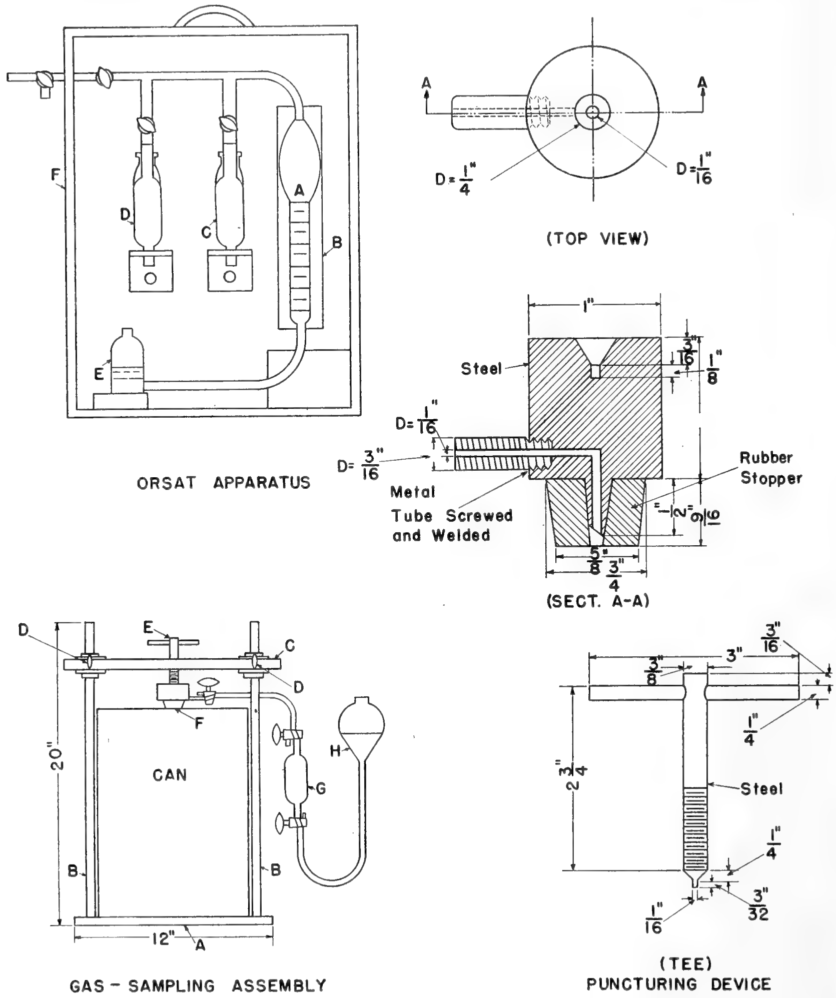

FIGURE 68.—Equipment for the analyses of the atmosphere of 5-gallon cans filled with dehydrated vegetables.

The puncturing device is forced down against the can. Contact is first made between the can and the stopper, followed by the puncturing of the can. The three cocks are now opened to permit some of the gases in the can to flow into *G* when the bulb *H* is lowered. The stopcocks are then closed.

For analysis of the gas, a 100-cc. gas burette is used with an enlargement between the 0 and 50-cc. marks, with no intermediate graduations in that range. The rest of the scale is divided into 0.2-cc.

units. Before the sample is transferred to the Orsat apparatus, a 100-cc. sample of air is analyzed for oxygen. The result should be close to 20.9 percent. The purpose here is to remove all oxygen and carbon dioxide from the apparatus and to test for leaks. It is essential to have the gas burette buffered against temperature changes by a water jacket, since otherwise changes in volume from one absorption to the next will be affected by an unknown error.

When gases low in carbon dioxide are to be analyzed, the residual gas (nitrogen) in the burette is ejected to the zero mark; the sample is then drawn in and analyzed. When the gas is high in carbon dioxide, 50 cc. of the nitrogen is retained in the burette in order to reduce the carbon dioxide concentration of the sample to be analyzed. The gas sampling bulb *G* is connected with the intake of the Orsat, a sample of gas (approximately 50 cc.) is taken into the burette *A* and the reading is recorded.

The carbon dioxide is absorbed by passage of the gas contents into and out of the caustic potash pipette until constant volume is reached. The burette reading is recorded. The volume of gas absorbed, multiplied by two, is the percentage of carbon dioxide present when a sample of exactly 50 cc. is analyzed. Next the residual gases are contacted similarly with the alkaline pyrogallol. This second loss in volume, multiplied by two, is the percentage of oxygen.

REHYDRATION TESTS

Rehydration tests should be developed in each plant so that a daily evaluation of the quality of the product can be made. The specific procedure for these tests must be developed in each plant in order that the equipment available, the amount of material to be tested, and the complications of plant organization and management can be

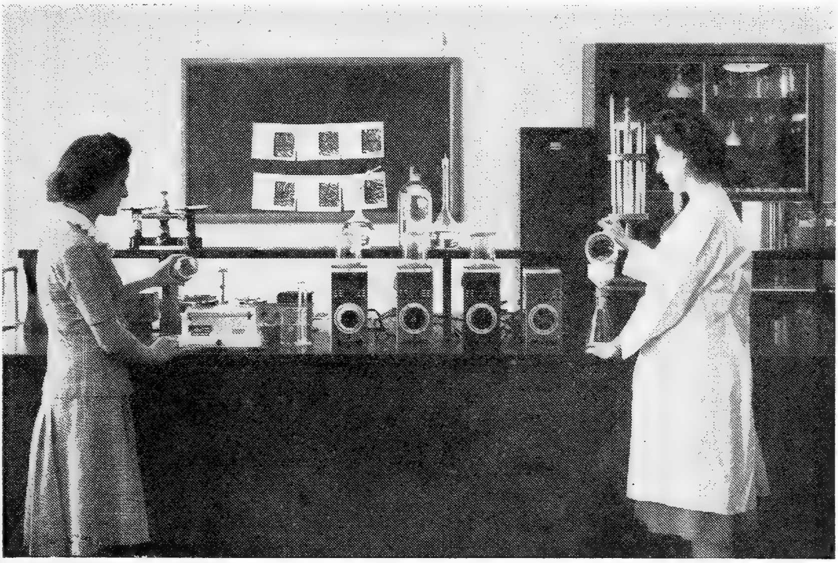

FIGURE 69.—Equipment used in rehydration studies. Left to right: Accurate weighing, precise control of heating, and complete draining.

duly considered. There are, however, certain fundamental principles which should be considered if these tests are to yield reliable information for plant control (fig. 69).

Methods

An amount of dehydrated material suitable to the equipment that is available is weighed directly into a glass beaker. Distilled water is added and the beaker is placed immediately on a heater. The content is brought to the boil at a fixed rate of heating and boiled for the scheduled number of minutes. In many instances soaking at room temperature before boiling produces a product of higher quality. The soaking time may vary from 1 hour to overnight. At the end of the boiling period the dish is removed and the contents quickly filtered. As soon as draining is complete the moist sample is weighed. The following procedure is used at the Western Regional Research Laboratory:

Weigh two 10-gm. samples of dry material on a torsion balance. Place in 600 ml. pyrex beakers, add 80 to 150 ml. of distilled water, cover each with a watch glass, place on electric heaters, bring to the boil within 3 minutes, and boil 5 minutes. The precise amount of water will vary with the material, time, and rate of boiling; excessive amounts of water should not be used. Remove from the heater and dump into a 75 mm. Büchner funnel which is covered with a coarsely porous filter paper. Apply gentle suction and drain with careful stirring for one-half to 1 minute, or until the drip from the funnel has almost disappeared. Do not dry by long suction. Remove from the funnel and weigh. Set the drained sample aside in a covered porcelain evaporating dish for quality tests. Repeat this test, and then rehydrate six other 10-gm. samples, boiling two for 10 minutes, two for 20 minutes, and two for 30 minutes. It will be necessary to use 20 to 30 ml. more of water for the last two tests than for the shorter boiling tests. Only small pieces will rehydrate in 5 minutes. Samples requiring more than 30 minutes of boiling are not likely to pass inspection for Government purchase.

A skillful technician will be able to operate four heating units and by staggering the time the filtering can be accomplished with one Büchner funnel. These dry materials are "water hungry" and 1 minute of variation in the time it takes to bring the sample to the boiling point, to remove the sample from the heater, or to complete the filtering, will cause significant errors in the final drained weights.

Calculations that can be made will vary with the data available. The rehydration ratio (table 14) can always be calculated. When the percentage of water in the dry sample is known, the percentage of water in the rehydrated sample can be calculated. When the percentages of water in the dry sample and in the undried sample are known, the coefficient of restoration of weight can be calculated. Calculations are illustrated in table 14.

TABLE 14.—*Methods of calculating ratios and coefficients of rehydration*

Determination made on sample	Ratio that may be calculated	Equation and calculation
W_O 9.45 (weight of original sample).	Drying ratio	$\frac{W_O}{W}=\frac{9.45\text{ pounds}}{1.25\text{ pounds}}=\frac{7.56}{1}$
W 1.25 (weight of dehydrated sample).	Rehydration ratio	$\frac{W_R}{W}=\frac{7.50\text{ pounds}}{1.25\text{ pounds}}=\frac{6.00}{1.00}$
W_R 7.50 (rehydrated weight)	Coefficient of restoration of weight.	$\frac{W_R/W}{W_O/W}100=\frac{(6.00)100}{7.56}=79.4$
A 87.5 (percent water in the original sample).	Rehydration ratio	$\frac{C}{D}=\frac{7.50}{1.25}=\frac{6.00}{1}$
B 5.3 (percent water in the dry sample). C 7.50 pounds, (drained weight of rehydrated sample). D 1.25 pounds (weight of dry sample used for rehydration test).	Coefficient of restoration of weight.	$\frac{C}{\frac{(D-BD)100}{100-A}}=\frac{7.50\times(100-87.5)}{1.25-(1.25\times0.053)}=\frac{(7.50)(12.5)}{(1.25-0.07)}=\frac{93.75}{1.18}=79.4$
E	Drying ratio	$\frac{(\text{Rehydration ratio})\ 100}{\text{Coefficient}}=\frac{6\times100}{79.4}=7.56$
F	Percent of water in the rehydrated material.	$\frac{7.50-1.18}{7.50}\times100=\frac{632}{7.50}=84.3$

Sources of Error

Needless to say, the technique of performing each test must be carefully standardized if comparable data of value are to result. The controllable factors of rate of heating, time held in the water, temperature of the water, ratio of water to sample, and the composition of the water can be readily standardized. It is not too simple to standardize the number of duplicated tests, the number of points on a given curve, or the number of curves that must be developed in order to gain adequate information concerning a sample.

Effective heat control and accurate timing are of major importance. The results shown in figure 70 (curve *a*) were obtained at room temperature (78° F.) with 1/8-inch sliced carrots, which regained approximately 41 percent of their original moisture in the first 20 minutes in the water. In the next 20 minutes they gained another 12 percent, and in 50 minutes they had regained 58 percent.

Other samples (curve *b*) at boiling temperature regained 69 percent of their moisture in the first 20 minutes, 10 percent more in the next 20 minutes, and at the end of 50 minutes they had regained a total of 81 percent. When soaked at room temperature before boiling (curve *c*) for a half hour, 75 percent of the original amount of water was regained during the first 20 minutes of boiling after soaking, and when soaked for a full hour, 82 percent was regained. In other words, soaking 1 hour and boiling 20 minutes was as effective in rehydration as was 50 minutes of boiling without soaking.

From this it is obvious that comparative tests are valuable only when time and temperature at which the material is kept in water are carefully controlled. Since all calculations of results are based on the drained weight of the rehydrated sample, only careful weighing and adequate draining will yield drained weights that are worth while. Draining through strainers, cheese cloth, or by gravity through filter paper yields rough approximations, but the Büchner funnel, with gentle suction and careful timing, has given the best results obtained thus far.

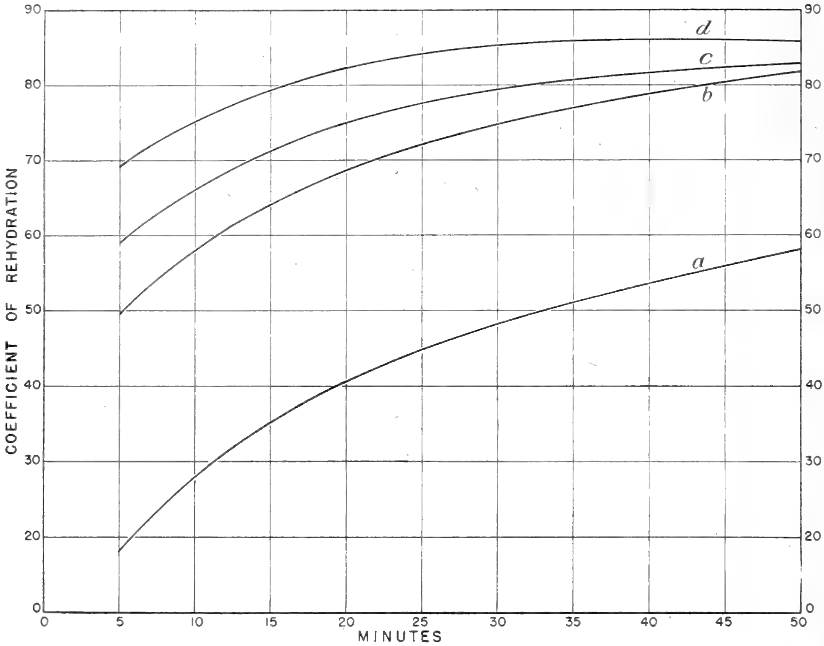

FIGURE 70.—Effects of soaking and boiling for various periods on the amount of water imbibed by dehydrated carrot slices. (See text for details.)

Composition and Amount of Water

In order to maintain effective rehydration throughout the test, adequate water must be supplied to the sample. It is impossible to maintain proper ratios of water to sample during the test if the rate of boiling varies from one test to the next.

The amount of solution to use for a given weight of material in any test may depend upon the immediate purpose of the test. Enough must be used to insure complete wetting of all parts of the sample. It may be desirable to shake or stir during the test period, in order to insure uniform wetting. When a sample is prepared for palatability tests, or for the purpose of demonstrating the preparation of the foods for homes or institutions, it may be desirable to use relatively small amounts of water and thus conserve taste, flavor, and nutrients, even though a lower coefficient of rehydration is attained. The nature of the solution is also highly important, because a variety of reactions may occur as a result of variations in composition. Taste, flavor, texture and color, one or all, may be affected.

There are four groups of pigments in fruits and vegetables which determine color: anthocyanins, flavonols, carotinoids, and chlorophylls. Red, purple, and black products, such as beets, plums, grapes, and red cabbage or onions, contain the anthocyanin pigments, which are highly soluble in water, and when excessive amounts are used and drained off, the color becomes poor. When acid is added to the solution, the color becomes pleasantly brighter and lighter, but in alkaline solution the colors become unpleasantly weak or dull and sometimes a complete change in hue, as from red to green or gray, may occur. In the presence of salts of tin and iron, these anthocyanins develop metallic lusters, such as occur in canned sour cherries or berries when the lacquer on the can is imperfect. These are unpleasant, although usually harmless.

White vegetables are colorless because the pigments are largely flavonols, and these are present in the colorless forms. When heated in mildly alkaline solution, the brilliant-yellow forms are produced. Thus yellowish-white or pale-yellow colors are typical of cooked cauliflower, potatoes, cabbage, and onions. These flavonol pigments are also soluble in water.

The orange or orange-yellow vegetables, such as corn, carrots, and rutabagas, contain large quantities of carotinoid pigments. These are not soluble in water and they are little affected by either acid or alkali solutions. However, the vegetables containing carotinoid pigments also contain flavonols and a minor change in color in alkaline solution, due to these latter pigments, will occur.

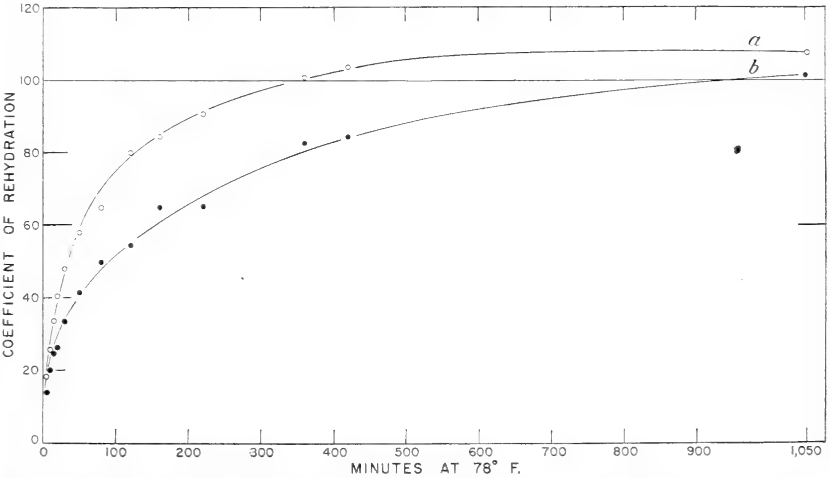

Figure 71.—Effects of slice thickness on coefficient of rehydration of carrots: *a*, one-eighth-inch slice; *b*, three-sixteenths-inch slice.

The dominant colors in green vegetables are the chlorophyll pigments. Chlorophylls are generally insoluble in water. The rich green color is destroyed in acid solution and the vegetable becomes a drab dull yellow or olive green, while in very mildly alkaline solution a lighter, more brilliant green is produced. Again, these vegetables contain flavonol and carotinoid pigments, which are invisible because of the green but which may contribute to the color when the green is destroyed.

Since both drainage and well waters may be mildly alkaline, the use of these in reconstitution tests may produce a light cream or yellow color in white vegetables, a brilliant green in green vegetables, a purple, green, or gray in red vegetables, but will cause little change in the orange or red of carrots and tomatoes. These mildly alkaline waters have little effect on texture, but strong alkalinity, such as is produced by adding sodium bicarbonate or sodium sulfite, causes an abnormal softening of the tissue which results in some instances in an unpleasant sliminess in the reconstituted product. Water supplies high in calcium and magnesium salts are common. Such water is likely to harden the skins on peas and lima beans.

Taste and flavor are affected only by relatively strong acids and alkalies, which are not encountered in ordinary usage.

Variation in the composition of drainage and well waters is an important matter. Indeed, the lack of uniformity from day to day or month to month may be a crucial difficulty in comparative testing in dehydration plants and should not under any circumstance be overlooked or disregarded. The cost of supplying a uniform quality of water, such as ordinary distilled, may be negligible as compared with the cost in time, material, and poor results obtained when tap water is used.

The size and shape of the individual pieces determine in part the amount of water that a given weight of dehydrated material will imbibe, in unit time and at unit temperature. For example, from one lot of carrots (fig. 71) two samples were dried, one sliced one-eighth inch, the other three-sixteenths inch thick. The former slice reached its original water content in approximately 3½ hours and the latter after 16 hours at room temperature (78° F.). These results show the importance of specific directions for home and institution use. In general the thick pieces require some soaking before boiling.

Serial Tests

No generalization can be offered here as to the number of duplicated tests that should be performed or the number of points on a rehydration curve that must be found. From the data presented in figure 72 it is obvious that single tests have little value. Figure 72 shows a set of six pairs of carrot samples of one variety dried at various temperatures until they had attained finished moistures of approximately 5.0 and 2.0 percent. They were sliced three-sixteenths inch thick and blanched 4 minutes. The problem was to determine whether or not the rate and effectiveness of rehydration had been influenced by the drying conditions and to correlate these conditions with optimum quality in the rehydrated sample. From preliminary studies it had been found that good samples of carrots were soft and tender after boiling 10 to 20 minutes, and also that by soaking overnight and then boiling 10 to 20 minutes a plumper, smoother slice with a higher coefficient of rehydration was obtained. It seemed advisable to try serial rehydration tests, in which time and temperature of rehydration varied from 10 and 20 minutes of boiling, without soaking, to soaking overnight (17½ hours) and then boiling 10 and 20 minutes.

As a means of determining extent to which failure to rehydrate might be caused by surface hardening of the pieces, samples were ground through 20-mesh sieves and then boiled without soaking for 10 and 20 minutes. Duplicate tests were made at each time-temperature interval. The average drained weight from these duplicate tests were used for calculating the coefficients reported in figure 72. This plan gave 14 rehydration tests on each sample.

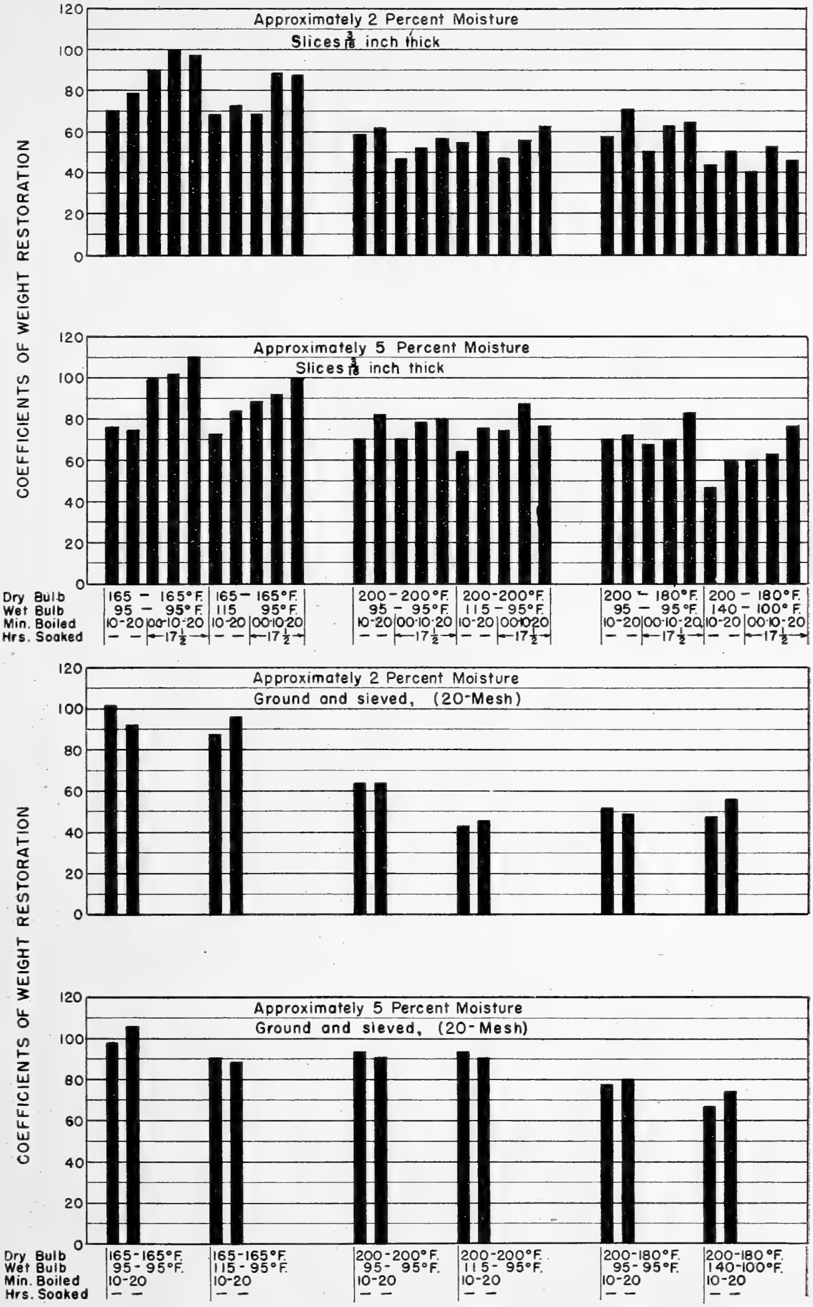

FIGURE 72.—Influence of temperature in the dehydrator and moisture content of the dry sample on the coefficient of weight restoration.

As shown in figure 72 there was a definite relationship between the temperature of drying, the finished moisture, the time in the drier, and the rate and effectiveness of rehydration. It was obvious that samples dried at a dry-bulb of 200° to 180° F. and a wet-bulb of 95° to 140° did not rehydrate so rapidly or so completely as did samples dried at lower temperatures. It will be noted that none of the samples dried at a minimum dry-bulb of 180° and over to less than 3 percent moisture rehydrated successfully.

Reducing the size of the piece by grinding increased the rate of rehydration in 9 out of 12 samples. After 10 minutes of boiling without soaking these ground samples were as well rehydrated as were the whole slices after 17½ hours of soaking and 20 minutes of boiling. Even in these ground materials the ability of the sample to rehydrate was decreased as the temperature in the drier was increased and as the finished moisture was decreased. Interpretation of these results would have been difficult or impossible if single tests had been made, and the final evidence was obtained only when the ground samples were shown to react in the same manner as the whole slices, thus indicating that rehydration failure was a characteristic of the entire tissue in the sample and was not merely case hardening or other surface effect.

Since the purposes of rehydration tests in the plant are to check the technique of drying and to insure high quality in the finished products at all times, a clear understanding of the distinction between rehydration and cooking should be made. In the strict sense, rehydration refers to the replacement of water in the dry sample, and when the material is held long enough at low temperature, a coefficient of rehydration of 100 will be attained and the shape of the sample will be completely restored. The only change in the sample results from imbibition of water. Cooking, on the contrary, is heat treatment of food for the purpose of bringing about physical and chemical changes, and the only criterion for degree of cooking in vegetables is a change from crisp, hard tissue to a soft, tender texture. The natural taste and flavor of the vegetable should be retained. It has been pointed out that the rate of rehydration is greatly accelerated at high temperatures; thus rehydration and cooking may proceed at the same time but at different rates, and the change in the chemical composition of the solids at 212° F. may result in complete disintegration of the tissue before rehydration is complete. Moreover, from the standpoint of quality testing there is a limit to the time that vegetables can be held if the finished product is to be edible. Off-flavors develop at less than boiling temperatures, and inedible products result from long boiling. The method for reconstitution, then, must take into consideration the relative time at which the sample will be held at room temperature and boiled. Establishing these times for each vegetable will make it possible to arrive at conditions that are compatible with optimum quality.

Nature and Condition of Material

It is difficult to explain the fact that products of one plant may rehydrate differently from those of another, even though the equipment and process are similar in the two plants. It is possible that variety, growing environment, maturity, and storage of raw materials affect the rate and effectiveness of rehydration as well as the color, taste, flavor, and texture of reconstituted products. In tests at the Western Regional Research Laboratory, rate of cooking, taste, flavor, and texture were drastically changed when carrots were permitted to become overmature, but the rate and completeness of rehydration were not affected. This is illustrated in table 15, which shows results from three varieties of carrots grown in one locality and dehydrated by one method. The code numbers, P767, P771, and P775 represent immature, high-quality carrots, the code numbers P119, P120, and P121, overmature and fair in quality of raw material. The rate and total degree of rehydration were essentially the same but the rate of cooking and the taste and flavor were definitely and consistently poor in the older samples.

Definition of Terms

Four expressions denoting the imbibition of water by the dehydrated products are commonly used: reconstitution, rehydration, refreshing, and cooking. Reconstitution implies restoration to the condition prior to dehydration in weight, size and shape, texture, color, flavor, composition, structure, and other observable factors. Thus the degree or completeness of reconstitution can be described only partially in quantitative terms, since it is difficult, and in some cases impossible, to make a quantitative evaluation of these constituent factors. While restoration of weight, color, form, and shape can be measured quantitatively, other factors such as taste, flavor, and texture are subject only to qualitative measures.

The restoration of the weight of the product through the imbibition of water is relatively easy to measure and, when the moisture content of the material is determined before and after dehydration, the percentage of restoration of weight can be calculated from the drained weight of the rehydrated sample. An example is shown in table 14. In this sample a rehydration ratio of 6.00 was equivalent to 79.4 percent of the original weight of the sample.

Methods for calculating certain related ratios are illustrated in table 14. The decision regarding calculation rests with the operator and will be influenced by the purpose of the experiment and the information that is available on the composition of the sample under study. Nevertheless, it is evident from the figures in table 16 that the rehydration ratio is not a true index of reconstitution. For instance, the four samples of dehydrated potato strips when rehydrated under exactly the same conditions gained 4.5, 4.7, 4.8, and 4.9 times the dry weight of the sample; the coefficients of weight restoration varied, however, from 78.5 to 124.3 percent. The gain in weight in rehydration was directly proportional to the solids in the dry sample, but to have attained the original composition the Nebraska Triumph sample required restoration to 85.0 percent water, while the Colorado Russet required only 75.5 percent.

TABLE 15.—*Reconstitution and quality in dehydrated carrots including 3 varieties*

Sample code [1]	Variety	Soaked	Boiled	Weight restoration	Form	Color [2]	Taste sweet [3]	Flavor natural [3]	Texture [3]		Final score
									Soft	Tender	
		Hours	*Minutes*	*Percent*							
P767	Long Imperator	0	5	68	Wrinkled	M. O.	+++	+++	++	++	Good.
P119	do	0	5	43	do	do	+	++	0	0	Poor.
P767	do	0	20	65	Fairly plump	do	+++	+	+++	+++	Good.
P119	do	0	20	54	do	do	+	++	++	+++	Fair.
P767	do	17½	5	103	Plump	do	+++	+++	++	+++	Good,
P119	do	17½	5	91	do	do	++	++	0	0	Poor.
P767	do	17½	20	128	do	do	+++	+++	+++	+++	Good.
P119	do	17½	20	104	do	do	++	++	+	+++	Fair.
P771	Red Cored Danvers	0	5	60	Wrinkled	do	+++	+++	+	+	Good.
P120	do	0	5	62	do	Str. O	+	+++	0	0	Poor.
P771	do	0	20	73	Fairly plump	M, O	+++	+	+	+++	Good.
P120	do	0	20	64	do	Str. O	++	++	+++	+++	Do.
P771	do	17½	5	100	Plump	M. O	++	+	+++	+++	Do.
P120	do	17½	10	83	do	Str. O	+	0	0	+	Poor.
P771	do	17½	20	90	do	M. O	++	+++	+++	+++	Good.
P120	do	17½	20	98	do	Str. O	+	0	0	+	Poor.
P775	Red Cored Chantenay	0	5	52	Wrinkled	M. Y. O	+++	++	++	++	Good.
P121	do	0	5	48	do	M. O	+	+	0	0	Poor.
P775	do	0	20	62	Fairly plump	M. Y. O	+++	+++	++	+++	Good.
P121	do	0	20	81	do	M. O	+	++	++	+++	Fair.
P775	do	17½	5	74	Plump	M. Y. O	++	++	+++	+++	Good.
P121	do	17½	10	83	do	M. O	++	++	0	+	Poor.
P775	do	17½	20	81	do	M. Y. O	+++	+++	+++	+++	Good.
P121	do	17½	20	107	do	M. O	++	+	+	+++	Fair.

[1] Young immature samples are P767, 771, and 775; old, overmature samples are P119, 120, and 121.
[2] M. O.=Moderate orange; Str. O.=Strong orange; M. Y. O.=Moderate yellow orange.
[3] 0=none or not; +=trace recognized by minority of jury; ++=mild and recognized by half or more of jury; +++=mild or pronounced and recognized by most or all of jury.

TABLE 16.—*Dehydration ratios versus coefficients of restoration of weight of various samples of potato*

[Potato strips 5/32-inch thick boiled 10 minutes, with no soaking]

Item	Colorado Russet	Katahdin	Colorado Pawnee	Nebraska Triumph
Water in original sample ---- percent	75.5	77.5	80.6	85.0
Water in dry sample ---- do	7.4	5.6	7.1	6.4
Weight of reconstituted sample ---- grams	47.0	48.0	45.0	49.0
Ideal weight of reconstituted sample ---- do	37.5	42.0	47.9	62.4
Coefficient of weight restoration	124.3	114.4	94.0	78.5
Rehydration ratio	4.7	4.8	4.5	4.9

Summary of Rehydration Tests

It is suggested that the following conditions be met by all who are interested in making rehydration tests:

Work out a time and temperature sequence suitable to the material being tested.

Determine the time of soaking and boiling that is compatible with optimum quality in each sample.

Always run a series of tests at various times and temperatures and evaluate the data on the rate of change in coefficient rather than on a single determination of a coefficient.

Start the test with at least enough water to submerge the pieces, but do not use so much water that excess amounts are present at the end of the test, especially when quality tests are being made on the samples.

Shake or stir if necessary to insure wetting of all the pieces during the test.

Control ther ate of heating so as to prevent rapid and variable losses of water while boiling.

Use unit heaters set up in such a way as to prevent rise in temperature from radiated or convected heat.

QUALITY TESTING

The human reaction to food is defined by four sensory perceptions. The appearance, the feel in the mouth, the taste and flavor, and the odor all contribute to the edibility of the food. Certain characteristics or qualities can be measured quantitatively: Examples are color, size, shape, and in some instances attributes of texture, such as resistance to shearing, breaking, and penetration. Other quality factors are measured by subjective techniques and at best are qualitative in character. Either one of three procedures may be used with more or less confidence in evaluating the purely subjective qualities of a given product. These are described below with certain suggestions as to their value.

One procedure is to reconstitute a series of samples by a standard method, call in 25 to 30 employees, and ask them which they like best. A refinement of this method is to assign an arbitrary number, let us say 10 for the best sample, 9 for the next best, 8 for the next and so forth, and ask the graders to rate the samples and assign numbers to them. The difficulties in this procedure are obvious. A serious objection is that it may be impossible to achieve. Few if any organizations can assign 25 to 30 employees for ½ to 1 hour each day for this work. When the make-up of the jury varies from 1 day to the next, the ratings on the samples will vary and nothing is accomplished by the test. Moreover, this method leaves one in ignorance of the reasons why one sample rates higher than another, and gives no clues as to when, where, or why quality is impaired.

A second procedure is to set up each day a standard sample, call in a relatively small but trained jury, and ask them to rate the new material as equal to, above, or below the standard. There are many advantages in this method. It yields concrete information, it takes relatively little time, and it makes possible a consistency in evaluations otherwise difficult to achieve. The limiting factor in its use for dehydrated products as in others is in the impracticability of maintaining a uniformly constant standard over any great length of time.

The third procedure, while it appears more complicated to the uninitiated, lends itself to standardization of quality in samples gathered over wide areas and over great lengths of time and hence is recommended as being satisfactory for plant testing. In this procedure each specific quality factor is graded, either subjectively by trained graders or objectively by some standardized technique. The plan, as developed at the Western Regional Research Laboratory, includes (1) color grading by direct comparison with Munsell standard color chips, (2) form, shape, and size by direct measurement and by direct comparisons of fresh-blanched and rehydrated pieces, and (3) subjective evaluations of taste, flavors, texture, odor, and consistency. Each jury includes three or more individuals. The rating sheets are arranged so as to permit checking of the quality point. A three-point scale is used (table 17). This procedure focuses the attention of the grader on the specific taste, flavor, and texture factors in the material, and when his opinions are properly summarized and combined with the results on color, form, shape, and consistency, a very satisfactory estimation of the quality of the sample is obtained.

TABLE 17.—*Organoleptic testing schedule: Data summary of jury of 10 opinions of quality on 2 samples of carrots*[1]

Characteristic	Scale	Number of opinions		Evaluation[2]	
		P767	P119	P767	P119
Sweetness	None	0	6	+++	+
	Mild	8	3		
	Pronounced	2	1		
Sourness	None	9	10	0	0
	Mild	0	0		
	Pronounced	1	0		
Bitterness	None	10	10	0	0
	Mild	0	0		
	Pronounced	0	0		
Characteristic flavor	None	1	3	+++	++
	Mild	8	7		
	Pronounced	1	0		
Softness	Crisp or firm	4	10	++	0
	Soft	6	0		
	Mushy	0	0		
Tenderness	Tender	8	0	++	0
	Hard	0	5		
	Tough or fibrous	2	5		
Change in flavor, acceptability	Strong or off but not stale	0	1	0	0
	Mildly stale	0	0		
	Pronounced staleness	0	0		
Edible quality	Not acceptable	0	2	+++	+
	Poor	1	7		
	Fair	1	1		
	Good	8	0		

[1] All samples were boiled 5 minutes without soaking.
[2] See Table 15 for full code.

Procedure for Quality Tests

Samples are reconstituted by methods already described. These are accumulated in sets of 10 to 20 individual samples. A small amount of the material is placed in a paper cup, and the cups are numbered in a series. Care is taken to avoid numbering that permits identification of the sample. Each juryman is provided with one complete set of samples, which he grades without consultation with his neighbor juryman.

The charts are collected and summaries are made of the opinions of the graders. The results are weighted qualitatively and reports are made on each quality factor (table 17).

For example, the carrot samples in table 15 were graded by 10 experienced graders and the results were summarized by the use of symbols 0 to + + +. The colors were determined and the degree of return in form was noted. Thus Sample P767 was sweet in taste, natural in flavor, moderately soft and tender when it had reached 68 percent of its original water content and had been boiled for 5 minutes without previous soaking. The color was good, and although the cubes were still somewhat wrinkled, the sample was reported good.

Several weeks later other lots of the same varieties of carrots were harvested, dehydrated, and tested organoleptically. In this instance there was little sweet taste in the sample, the flavor was natural but weak, and it was crisp and tough after 5 minutes of boiling. This would have been reported poor but since it was obviously underdone, other sets were prepared by boiling 20 minutes without soaking and 5, 10, and 20 minutes after soaking overnight (17½ hours). When all the tests were summarized, it was found that 20 minutes of boiling without previous soaking yielded the maximum quality in the samples. Long soaking gave higher coefficients, and in two instances equivalent quality, but in sample P120 the quality after soaking 17½ hours and boiling 20 minutes was poorer than when boiled without soaking. It lost taste and flavor and became very turgid and hard.

Jury Selection and Training

All jurymen should be trained to recognize the qualities in a standard sample before they are permitted to pass on unknown samples, and, when available, standard samples should be included in the daily series. The following suggestions may be helpful. All graders or jurymen should be persons who like fruits and vegetables; who have poise, intelligence, and integrity; whose living and eating habits are reasonably regular; whose health is reasonably good (certainly free from gastro-intestinal diseases). A jury of five or more is recommended.

The testing should be carried out over a short period of time, and the room should be quiet enough to permit concentration on the part of the grader. Under no circumstance should a grader be interrupted or distracted while rating the samples. The grading should be done in a room free from smoke, stale odors such as come from pipes and cigarette butts, old samples, and disagreeable chemical reactions.

The grading of odor is difficult and for the most part unsatisfactory, but offensive or stale odors should be noted by the jurymen and given due weight in the final score for the sample.

Summary of Quality Testing

Methods of reconstitution must restore and preserve to a maximum the appearance, edibility, and nutritive value of the product. Since dehydrated vegetables are blanched before drying, the restored material will have the characteristics of a partially cooked vegetable.

Color, taste, flavor, and odor are highly concentrated during dehydration, but because of losses during blanching and drying, optimum quality in the rehydrated material is usually obtained before all the water has been replaced in the material.

Because of variations in raw material and techniques of blanching, drying, and storage, it is recommended that each plant provide staff and facilities for daily rehydration and quality tests on the samples being produced.

PROCESSING COSTS

The subject of operating costs is discussed below in two sections: (1) Labor requirements and (2) segregation and analysis of processing costs. The general problems of labor distribution and labor requirements are discussed first and certain aspects of labor which are closely connected to segregation and analysis of costs are considered further under the latter heading.

Labor Requirements

The number of employees in a dehydration plant is by no means fixed, and, because a large number of factors affect labor use, preliminary estimates of labor requirements are usually rough approximations. Labor requirement is affected by type of process, degree of mechanization, efficacy of equipment, effectiveness of plant lay-out, proper balance between operating steps, condition, variety, and grade of raw material, specifications for finished product, labor laws and customs, working conditions, ability and training of employees, safety measures, method of pay, morale, and operators' individual preferences and policies.

Not all of these factors can be evaluated in advance. Observations made in canneries and dehydration plants and the opinions of experienced plant operators are the best source of information on this subject. The discussion presented here has been developed largely from such sources.

Table 18 shows the approximate labor distribution in dehydration plants of moderate size, handling about 50 tons per day (unprepared basis) of 7 vegetables important in the dehydration program. The trimming, sorting, and inspection labor varies almost in direct proportion to the size of the plant. Thus a 100-ton plant drying potatoes can be expected to require from 60 to 100 women on the trimming belt; a 10-ton plant, 6 to 10. This direct relationship does not hold true for the other operations. As size of plant increases, the labor requirement per unit of output for these other operations decreases. Because of the need for at least one or more employees for each of many operations, regardless of the throughput at those points, the smaller plants are at a disadvantage as compared to the larger ones, which can make more efficient use of labor. Except for sorting, trimming, and blanching, the labor requirements are substantially the same for these 7 vegetables.

TABLE 18.—*Approximate labor requirements*[1] *per shift for various vegetables in a dehydration plant handling 50 tons per day, unprepared basis (dehydrator labor based on use of truck-and-tray tunnel driers)*

Job	Table beets	Cabbage	Carrots	Onions	Potatoes	Rutabagas and turnips	Sweetpotatoes
Feeding to preparation line	1–2 M	1–2 M	1–2 M	1–2 M	1–2 M	1–2 M	1–2 M
Operating autoclave, sizer, and/or peeler	3–5 M	—	0–1 M	0–1 M	0–1 M	0–1 M	0–1 M
Sorting and trimming	20–25 F	5–10 F	20–25 F	25–35 F	30–50 F	20–25 F	25–35 F
Spreading on blancher belt	—	0–2 F	0–2 F	—	0–2 F	0–2 F	0–2 F
Placing trays on conveyor	1 M	1 M	1 M	1 M	1 M	1 M	1 M
Spreading on trays	1–2 F	1–2 F	1–2 F	1–2 F	1–2 F	1–2 F	1–2 F
Loading cars	2 M	2 M	2 M	2 M	2 M	2 M	2 M
Moving cars and operating drier	2 M	2 M	2 M	2 M	2 M	2 M	2 M
Scraping trays	2–4 M	2–4 M	2–4 M	2–4 M	2–4 M	2–4 M	2–4 M
Final inspecting	2–6 F	4–8 F	2–6 F	4–8 F	4–8 F	2–6 F	2–6 F
Packaging, crating and warehousing[2]	3–4 F 2–3 M	3–4 F 2–3 M	3–4 F 2–3 M	3–4 F 2–3 M	3–4 F 2–3 M	3–4 F 2–3 M	3–4 F 2–3 M
Other:							
Foreman	1	1	1	1	1	1	1
Forewoman	1	—	1	1	1	1	1
Helpers, cleanup, tray washer, carpenters, maintenance	4–6 M	4–6 M	4–6 M	4–6 M	4–6 M	4–6 M	4–6 M
Total number per shift:							
Men	17–25	14–20	14–21	14–21	14–21	14–21	14–21
Women	26–37	13–26	26–39	33–49	38–66	26–39	31–49
Foreman	1	1	1	1	1	1	1
Forewoman	1	—	1	1	1	1	1

[1] M=male; F=female.

[2] Labor requirements for packaging depend upon type of container used. Labor figures shown here are based upon the use of 5-gallon cans, automatic sealing machines, and prefabricated cartons, boxes, or crates. The use of metal foil containers or other types of packages will involve a different labor set-up.

The method of peeling materially affects the number of trimmers needed. Abrasion peeling of potatoes may require as many as 50 women per shift in a plant handling 50 tons per day. Lye peeling may reduce that number to between 30 and 40. Flame or radiant-heat peeling, brine peeling, or other peeling methods may also result in a lower labor requirement for trimming.

The type of dehydrator affects labor requirements. A 50-ton tunnel requires from 10 to 15 employees per shift for loading and stacking trays, moving cars, operating the drier, scraping trays, and washing trays. If a conveyor-type dehydrator is used, and a suitable mechanical arrangement is available for spreading the product evenly over the conveyor belt, from 2 to 4 employees may be necessary to handle the drying operations in a plant of this size.

Segregation and Analysis of Processing Costs

Direct operating charges are much greater than capital charges in a vegetable-dehydration plant, since in many plants the monthly labor, raw material, and packaging costs are more than the original capital outlay for buildings and equipment. The present section deals with the problem of proper segregation and analysis of the various operating charges. Its purpose is to assist operators in developing a system of cost analysis that will indicate accurately the relative importance of various cost factors and the effects of changes in operating procedures.

A proper segregation and analysis of operating costs is of value to the plant operator as a means of (1) comparing the operating costs for different methods of preparation, drying, and packaging (particularly valuable to prospective dehydrators); (2) comparing different raw materials; (3) obtaining accurate control over all phases of operation; (4) keeping the operator informed on current production costs; and (5) providing a proper and detailed record of operations for future reference or audit.

In order to simplify their consideration, operating costs are divided into the following main groups: Raw material cost, preparation cost, drying cost, packaging and warehousing costs, indirect and overhead costs (accounts must be set up in which these charges are accumulated before distribution to the first four groups).

This is a convenient grouping for discussion, since it covers the major steps most commonly followed in plants that handle vegetables or fruits. Each major step can be considered separately, and factors peculiar to that step need not be confused with any other. From an operating standpoint also, such a grouping has merit. In keeping these costs separate, the operator can compare various methods of operation. If tunnel drying on trays is to be compared with drying on a conveyor, costs associated with the actual drying steps are readily available for comparison.

For some purposes, a further break-down is desirable. For example, the problems involved in peeling and trimming present a broad field for study. The relative advantages of lye peeling, brine peeling, heat peeling of various kinds, abrasive peeling, and hand peeling, together with related trimming costs, warrant much consideration. For the purpose of making such studies, a detailed break-down of preparation costs is valuable. For example, peeling, trimming, and blanching may each be given separate consideration.

RAW-MATERIAL COST

As a rule, raw material is the largest single item of cost in a vegetable- or fruit-dehydration plant. In some instances, it may amount to as much as 50 percent or more of the total cost per dry pound. Any attempt to reduce operating costs should, therefore, include careful study and control of the raw material. Variety, growing conditions, time of harvest, handling, and storage, all of which affect the quality of raw product, are extremely important in determining costs, yield, and quality of dry product. An operator should contract for his raw material well in advance of actual need, so that the production, transportation, and storage will be under his direct supervision and the product delivered to him will be the best obtainable.

The cost of raw product is magnified in the cost of the dry product to the extent of the overall shrinkage ratio.[17] On cabbage, a cost increase of only a dollar a ton will result in an increased cost of almost 1 cent per dry pound. On a given vegetable, the quality and condition of the raw material will determine largely the overall shrinkage ratio. It is advisable in many cases to pay relatively high prices in order to obtain high-quality foods, since lower preparation losses and frequently lower drying losses will increase the yields and more than offset the higher purchase price.

A careful analysis of the interrelated variables (raw-material grade, preparation losses, trimming costs, and drying ratio) is essential if the

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[17] The "overall shrinkage ratio" is the ratio of the weight of unprepared raw material to the resultant weight of the finished product. The "drying ratio" is the ratio of the weight of prepared material entering the drier to the weight of the same material leaving the drier. The proper use of these terms helps to avoid confusion.

most economical combination of raw materials and preparation methods is to be attained. Graphs such as those shown in figures 73 and 74 can be conveniently used to study the combined effect of these variables. For example, we find from figure 73 that a raw material which has a 20-percent preparation loss and a 5 to 1 drying ratio yields 320 pounds of dry product per raw ton. If the combined raw-material

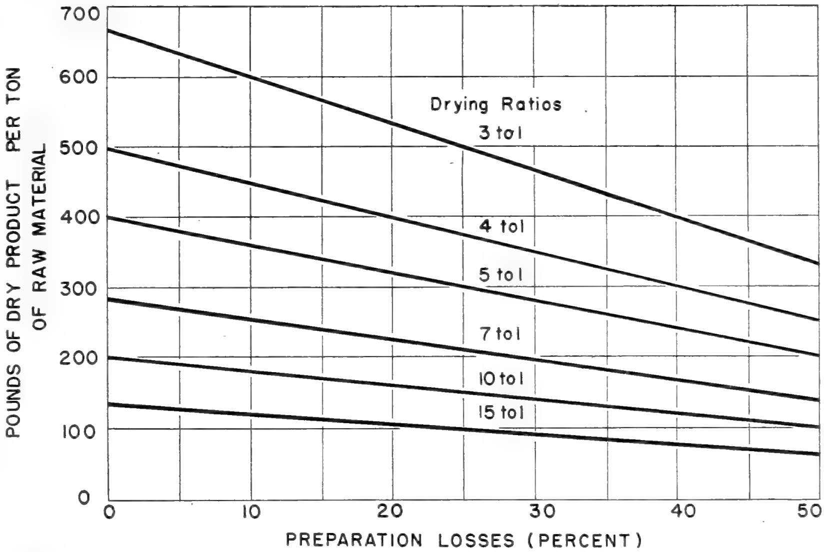

FIGURE 73.—Yields of dry product at various preparation losses and drying ratios.

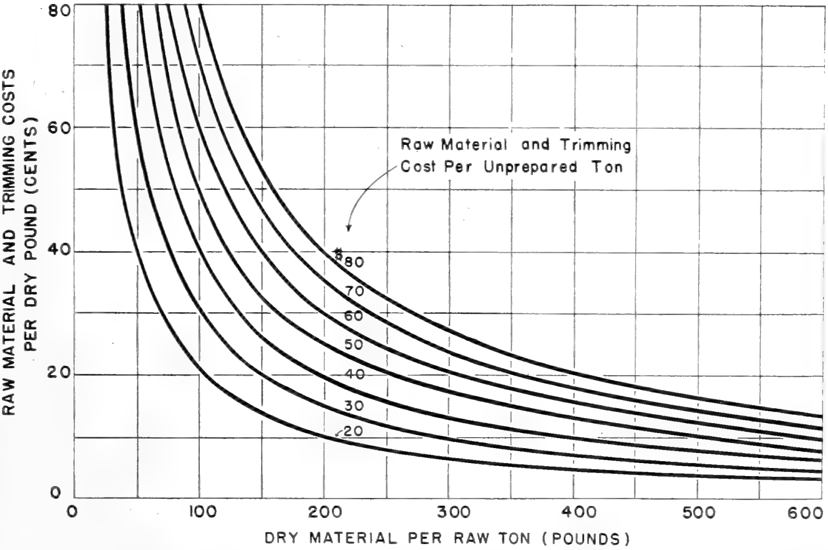

FIGURE 74.—Raw material and trimming costs per dry pound at various yields of dry product.

and trimming cost is $60 per unprepared ton, we find (fig. 74) that the cost per dry pound is 19 cents.[18] If a cheaper raw material, costing only $50 per ton including trimming, is found to have a 30-percent preparation loss and a 5½ to 1 drying ratio, the charts indicate that this material also costs 19 cents per dry pound for raw material and trimming. Quality of final product may be the deciding factor in this case, if waste disposal is not an important problem. The operator will find that similar graphs are applicable to other operating problems.

Certain assumptions must be made and some caution exercised in the use of graphs such as those shown in figures 73 and 74. For the purpose of these graphs, it is assumed that all changes in weight during preparation, either through loss of material or changes in water content, are included in the preparation loss.

When wood trays are being used in the determination of preparation loss, errors may be caused by variation in tare weight of the trays, caused by variations in wetness of the wood. This difficulty can be largely overcome in test runs by wetting the trays before loading and using the weight of the wet trays as the tare weight. The problem is obviated by the use of metal trays.

The changes in weight from the raw material, as purchased, to the prepared material, ready for drying, include such items as dirt removed in preliminary washing, culls graded out, the actual preparation losses (peeling, coring, trimming, etc.), and leaching losses or water pick-up during the peeling, cutting, washing, and blanching. Excessive washing after cutting and especially after blanching may result in losses of 10 percent or more on potatoes.

In test runs, the drying ratio should be determined on the plant-prepared material, ready to go to the dehydrator, rather than on small samples. (Determination of dry ratios on samples of different raw materials is, nevertheless, a valuable means of making preliminary comparisons.)

Inspection losses on the final product are frequently so small that they can be neglected. If inspection losses are large enough to warrant a correction on the yield, this correction can be made by a deduction from the yields shown by the graphs for given values of preparation loss and drying ratio. It may be impossible to determine this in advance of actual plant operations. If fines are removed from the dry product before packaging, they may be either a total loss or may have a market value at a lower price. This will require a further correction to the yield. The simplest procedure is to determine yield after removal of the fines and credit the operations separately with any return obtained from the sale of the fines.

Failure to take account of the many factors tending to decrease the final net packed weight may result in ruinously erroneous conclusions regarding the probable over-all weight shrinkage from raw material to final product. Solution of the problem outlined above should, however, be relatively easy in an operating plant, since it can be based on actual operating tests.

A greater danger lies in the assumptions that are likely to be made in planning for a new plant where previous experience is not available on the raw material or process. The only data will be hypotheti-

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[18] The preparation loss used for this purpose must be an overall preparation loss, determined in actual test runs, and must take account of the possible sources of error discussed in the following paragraphs.

cal figures—moisture content of the raw material and estimated peeling and trimming losses, with perhaps allowances for inspection and screening losses. Suppose that a mixture of No. 1 and No. 2 potatoes is being used. The moisture content is found to be 78 percent, corresponding to a drying ratio of 4.3 to 1. The total loss from raw to finished product is assumed to be 25 percent, giving an over-all shrinkage of 5.7 to 1. Few people would assume a loss of 39 percent, which would raise the ratio to the 7 to 1 value frequently found in actual operation on raw material of this character. The difference may lie in dirt and cullage losses and leaching losses during preparation or failure to use representative material in determining the moisture content.

The cost of raw material includes the following items: Purchase price, brokers' fees and other costs incidental to purchase, hauling charges, costs of handling and storing prior to delivery to preparation line, salaries and expenses of personnel engaged in raw material purchase, and other expenses, including indirect and overhead costs.

PREPARATION COST

The preparation of a vegetable or fruit for drying is usually understood to include all of the steps that take it from storage through the last operation prior to loading on trays or belts, or into a kiln, for drying. If the product is blanched or sulfured on trays, tray loading is a drying cost and blanching and sulfuring expense is still a preparation cost. The major steps for most fruits and vegetables are presented below. They may be in proper order for some but not for others; certain of the steps will not be necessary in all cases, and additional operations may be needed on some products: (1) Feeding to preparation line, (2) sorting, (3) washing, (4) sizing, (5) peeling, (6) trimming, (7) slicing, dicing, cutting, stripping, ricing, etc., (8) washing, (9) blanching, sulfuring, or checking, and (10) disposing of waste.

Two factors in preparation largely determine the economy of operation: The judicious use of labor and the yield of prepared product from unprepared. Equipment costs are also important but are usually small in the long run, compared to the cost of labor displaced. Total labor may run as high as a third of all processing costs, and preparation labor is by far the largest single cost item or combination of items in preparation alone. Capital and operating charges on preparation equipment amount to only a small fraction of preparation labor in most vegetable- and fruit-dehydration plants. Studies on labor efficiency and labor replacement offer a most promising means for effecting reductions in operating costs.

Increased output per employee may be achieved by proper training and intelligent supervision. A piece-work or bonus system, coupled with rigid supervision and inspection, usually results in lower labor costs, especially in the trimming operation. A reduction in the number of workers can often be made by more uniform operation, the elimination of process steps, or the installation of labor-saving equipment. The importance of the last point is sometimes underestimated even in large plants.

Figure 75 shows roughly the value of equipment that can be purchased and operated with specified amounts saved in labor costs. The following assumptions have been made: Interest and taxes, 10 percent per year; repairs and maintenance, 10 percent per year for 1-year and 2-year write-offs, 15 percent per year for 5-year, and 20 percent per year for a 10-year write-off; hourly operating cost per $1,000 of investment, 10 cents; number of hours operated per year, 24 hours per day, 200 days per year. A decrease in labor costs of only $1 per hour will pay the operating and capital charges on equipment conservatively estimated as costing $4,000 to $5,000 with a 5-year write-off.

A uniform flow of product along the preparation line is essential for most economical operation. An even flow requires fewer employees and smaller equipment than does an irregular or spasmodic flow. Losses caused by temporary shut-downs are often large. Most items of cost continue during shut-downs, with the exception of those for raw material and packaging supplies not used and a small amount for utilities. It may not be practical to save labor costs by dismissing the help, because it is usually impossible to anticipate the length of a shut-down.

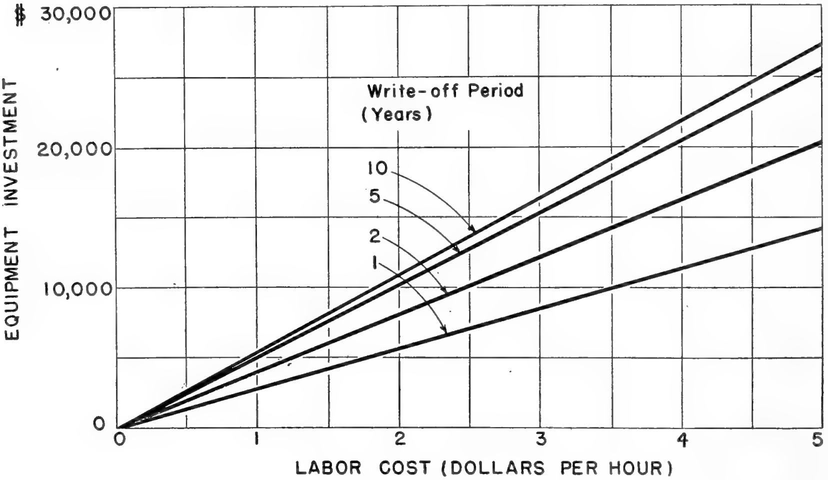

Figure 75.—Equipment investment justified by savings in labor costs.

The amount of loss due to a shut-down may be roughly estimated by assuming that the sale value of the lost production less the cost of materials saved (raw material and containers) is an actual loss. For example, a shut-down of the preparation line, due to a shortage of raw material, results in a loss of 20 cents for each pound of lost production if the selling price of the product is 35 cents per pound and the combined raw-material and container costs are 15 cents per pound. This amounts to $100 per hour in a plant which normally turns out 500 pounds of finished product per hour.

Careful treatment of the raw product through all stages of preparation reduces the processing cost per dry pound by increasing yields. The two steps in preparation that offer the best opportunity for decreasing material losses are peeling and trimming.

The care and skill exercised by trimmers have an important effect on material losses. Proper training and supervision are especially important for trimming personnel. The plant operator should know at what point a further increase in trimming rates results in excessive raw-material losses. A saving of only 5 percent of the raw product by slower and more careful trimming will pay for the employment of two extra employees if the hourly labor cost per employee is $1, including overhead, and the plant is handling 1 ton per hour of raw product costing $40 per ton. If the plant processes 5 tons per hour, 10 additional trimmers could be justified by a 5-percent material saving.

The efficient operation of each item of equipment is most essential. The manner in which a machine is operated may cause variations in processing costs greater than the capital charges on the machine. For example, some cutters produce a considerable amount of chaff unless fed at optimum rate.

The problem of waste disposal is properly a part of preparation. The quantity and kind of waste are largely the result of the preparation method. For instance, flame or radiant-heat peeling causes a less serious sewage problem than abrasive peeling because the quantity of waste is much smaller. Lye peeling results in a waste product that may require special treatment, deepnding upon the disposition made of it.

Preparation costs include the following main items: Labor, equipment charges, utilities (mainly water, power, and fuel for providing steam), chemicals such as salt, lye, sulfur, etc., waste disposal (cost of disposal or credit for sale of peels, trimmings, etc.) and other expenses, including indirect and overhead costs.

DRYING COST

Drying covers the processing operation after delivery from the blancher up to and including delivery from the finishing bins. If no bins are used, drying ends with emptying of the trays or belts. Equipment charges are a larger proportion of the drying cost than is the case with preparation. For most vegetables, a few employees operate a piece of drying equipment that may cost as much as all of the preparation equipment put together, or even more. For some fruits, the ratio of drying cost to preparation equipment cost is even greater, especially for those requiring no peeling or cutting.

A minimum of labor costs can be achieved by the use of a continuous-belt drier, or, with the tray drier, the installation of all practical labor-saving methods and devices.

The cost of heat and power for many products may not amount to over 1 cent per dry pound. Direct-fired air heating is nearly always more efficient than indirect heat where suitable fuel is available. The installation of properly designed units is an engineering problem, but the capital charges and operating costs of these units can be a subject of cost analysis even before the unit is built or operated. Allowable temperatures, maximum or minimum humidities, and desirable drying times are predetermined technologically. Within the range of these conditions, the plant operator must find the most economical point of operation.

Figure 76 shows the approximate cost of heat and power for evaporating 100 pounds of water with different percentages of recirculation, with an outside temperature of 60° F. and 60 percent relative humidity. The following assumptions have been made: Cost of fuel oil, 3 cents per gallon, or coal, $5.50 per ton; cost of electricity, 1½ cents per kilowatt-hour; 60 percent fuel efficiency; constant air flow; maintenance of a constant wet-bulb depression at the cool end. Under the conditions mentioned, 75 percent recirculation is most economical. For any particular vegetable, and for different weather conditions, similar charts can be drawn. It is possible that minimum costs may not be obtainable under conditions that are optimum from the standpoint of product quality. The plant operator must often determine the best compromise among the three factors: Product quality, product cost, and plant output.

Discussions of operating costs usually assume a balance between the preparation line and the dehydrator. Obviously, the balance is disturbed by anything that changes the capacity of either one. For example, the output of the preparation line may be increased by an improvement in raw material, thus increasing the amount of material fed to the drier. If the dehydrator has reserve heating capacity, it may be possible to dry the increased quantity by decreasing the amount of air recirculated, thus shortening the drying time. (The alternative expedient of increasing tray loading may be undesirable from the standpoint of quality because of increased drying time, and, for the same reason, may not increase the quantity of material the dehydrator will dry in a given period of time.) The increase in fuel cost due to lower heat efficiency will usually be more than offset by the value of the increased output of the plant. In other words, if there is no shortage of fuel, fuel economy is relatively less important than labor efficiency.

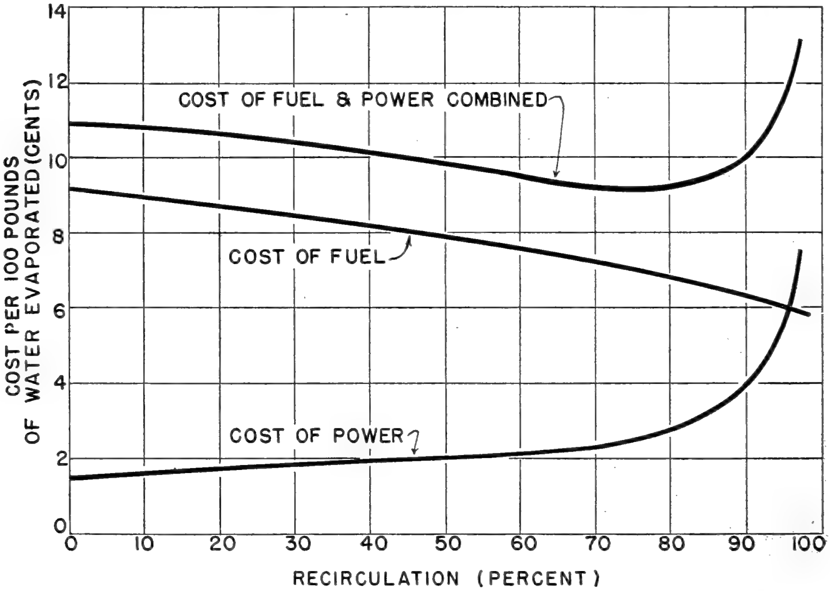

FIGURE 76.—Cost of evaporating water in air-blast dryer at various percentages of recirculation.

The main items of drying expense, without regard to order of importance, are: Labor, equipment charges, fuel and power costs, and other expenses, including indirect and overhead costs.

Packaging and Warehousing Costs

For purposes of discussion, several operations are included in this group, as follows: (1) Final inspection; (2) air desiccation; (3) grinding; (4) packaging, filling, replacing air with inert gas, sealing, labeling, boxing or crating, and (5) warehousing or car loading.

Final inspection might logically be included in a separate group. It is, however, a relatively minor operation and for that reason is included here insead of in an independent classification. The number of inspectors varies according to the quality of the raw material, care used in preparation, and quality of drying, as well as the requirements of the purchase specifications or grade standards.

The main items of packaging expense, not necessarily in order of importance are: Containers, labor, utilities (including air desiccation), inert gas, equipment charges, and other expenses, including indirect and overhead costs.

Indirect and Overhead Costs

Indirect and overhead costs are included together, since there is apparently little to be gained in attempting to separate them. Costs that cannot be directly and wholly charged to any of the groups mentioned previously are included in this group as follows:

Administrative salaries and expenses, interest on investment and taxes, depreciation of plant and equipment, rental of building or equipment not chargeable directly, insurance on plant (labor insurance is a cost of labor), factory clerical salaries and expenses, laboratory salaries and expenses, equipment and building repairs and replacements not chargeable directly, fire extinguishing apparatus and other safety precautions, laundry, clean-up labor and janitorial services, vacation labor, first-aid supplies and expenses, transportation of help, miscellaneous supplies and expenses.

In distributing these various expenses to the different steps of operation each item of overhead or indirect cost theoretically should be analyzed and prorated separately on a basis equitable for that particular expense. In actual practice, it is not always practicable to do this. It is advisable, however, to handle as many items as possible in this manner. For those items not handled separately, a grouping is satisfactory. Laundry, vacation labor, transportation of help, and other similar charges can be equitably distributed on a labor basis. Depreciation, insurance and taxes, maintenance and repairs, etc., are more logically spread on an equipment investment or other similar basis.

Individual treatment of each item is also preferable in distributing indirect and overhead expenses among the various products handled. This method of distribution should be used wherever practical. Charges not so handled can be grouped and distributed on a basis equitable for the group, such as one or more of the following: Value of finished product, time dehydrator is used on each product, quantity of material produced, direct labor cost, and raw-material cost.

The size of the dehydration plant is a factor determining the degree of detail used in prorating each item. In a small plant, too much attention to such details is unwise. In a large plant, considerable detail is warranted.

Estimated Processing Costs in Vegetable Dehydration

Table 19 presents a partial summary of estimated processing costs in vegetable dehydration, and table 20 shows labor cost per dry pound. The cost elements included are raw material, direct and indirect labor, packaging, and utilities.

TABLE 19.—*Estimated costs per dry pound of dehydrated vegetables, exclusive of overhead costs and profits, in a dehydration plant handling 50 tons per day, unprepared basis*

Item	Table beets	Cabbage	Carrots	Onions	Potatoes	Rutabagas or turnips	Sweetpotatoes
Form in which prepared	Slices	Shreds	Cubes	Slices	Strips	Slices	Slices
Pounds per 5-gallon container	8	7	17	12	10	12	12
Assumed overall shrinkage ratio	13 to 1	20 to 1	11 to 1	11 to 1	7 to 1	10. 5 to 1	5 to 1
Processing costs per dry pound:	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Labor, direct and indirect[1] [2]	10. 0–14. 5	10. 5–16. 5	8. 0–11. 5	9. 0–13. 0	6. 0–10. 0	7. 5–11. 0	4. 0–6. 0
Containers [3]	5. 0	5. 5	2. 5	3. 5	4. 0	3. 5	3. 5
Utilities [4]	1–2	1–2	1–2	1–2	1–2	1–2	1–2
Total	16. 0–21. 5	17. 0–24. 0	11. 5–16. 0	13. 5–18. 5	11. 0–16. 0	12. 0–16. 5	8. 5–11. 5
Raw material costs per dry pound:							
Cost at $20 per ton	13. 0	20. 0	11. 0	11. 0	7. 0	10. 5	5. 0
Cost at $25 per ton	16. 5	25. 0	14. 0	14. 0	9. 0	13. 0	6. 5
Cost at $30 per ton	19. 5	30. 0	16. 5	16. 5	10. 5	16. 0	7. 5
Cost at $35 per ton	23. 0	35. 0	19. 5	19. 5	12. 5	18. 5	9. 0
Cost at $40 per ton	26. 0	40. 0	22. 0	22. 0	14. 0	21. 0	10. 0
Cost at $45 per ton	29. 5	45. 0	25. 0	25. 0	16. 0	23. 5	11. 5
Total costs per dry pound not including overhead costs or profit: [1]							
Raw material at $20 per ton	29. 0–34. 5	38. 0–44. 0	22. 5–27. 0	24. 5–29. 5	18. 0–23. 0	22. 5–27. 0	13. 5–16. 5
Raw material at $25 per ton	32. 5–38. 0	43. 0–49. 0	25. 5–30. 0	27. 5–32. 5	20. 0–25. 0	25. 0–29. 5	15. 0–18. 0
Raw material at $30 per ton	35. 5–41. 0	48. 0–54. 0	28. 0–32. 5	30. 0–35. 0	21. 5–26. 5	28. 0–32. 5	16. 0–19. 0
Raw material at $35 per ton	39. 0–44. 5	53. 0–59. 0	31. 0–35. 5	33. 0–38. 0	23. 5–28. 5	30. 5–35. 0	17. 5–20. 5
Raw material at $40 per ton	42. 0–47. 5	58. 0–64. 0	33. 5–38. 0	35. 5–40. 5	25. 0–30. 0	33. 0–37. 5	18. 5–21. 5
Raw material at $45 per ton	45. 5–51. 0	63. 0–69. 0	36. 5–41. 0	38. 5–43. 5	27. 0–32. 0	35. 5–40. 0	20. 0–23. 0

[1] The low limit of labor cost is a summation of the low estimates for each individual operation, as shown in table 18; it is very unlikely that any plant will operate with an absolute minimum of labor in all operations.

[2] See table 20 for cost details.

[3] The cost of packaging includes 25 cents for a single 5-gallon can and 30 cents for the wire-bound wood box holding 2 cans; the total per can is 40 cents.

[4] In natural gas areas, many plants are operating at a cost of less than 1 cent per dry pound for utilities: Gas, electricity and water. Utilities may run considerably more than that amount in high-cost regions. Such costs have been roughly estimated to range between 1 and 2 cents per dry pound. A more accurate estimate is not warranted since the plant location, type of fuel, and operating procedures are not specified.

TABLE 20.—*Labor cost per dry pound in vegetable dehydration plants handling 50 tons per day, unprepared basis*

Vegetable	Output per hour, dry basis[1]	Labor cost per hour							Labor cost per dry pound
		Direct and supervisory [2]					Indirect[3]	Total	
		Men	Women	Foreman	Forewoman	Total			
	Lb.	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Dol.*	*Cts.*
Table beets	320	12. 75–18. 75	15. 60–22. 20	1. 25	0. 85	30. 45–43. 05	2. 05–2. 55	32. 50–45. 60	10. 0–14. 5
Cabbage	210	10. 50–15. 00	7. 80–15. 60	1. 25	------	19. 55–31. 85	2. 05–2. 55	21. 60–34. 40	10. 5–16. 5
Carrots	380	10. 50–15. 75	15. 60–23. 40	1. 25	. 85	28. 20–41. 25	2. 05–2. 55	30. 25–43. 80	8. 0–11. 5
Onions	380	10. 50–15. 75	19. 80–29. 40	1. 25	. 85	32. 40–47. 25	2. 05–2. 55	34. 45–49. 80	9. 0–13. 0
Potatoes	600	10. 50–15. 75	22. 80–39. 60	1. 25	. 85	35. 40–57. 45	2. 05–2. 55	37. 45–60. 00	6. 0–10. 0
Rutabagas or turnips	395	10. 50–15. 75	15. 00–23. 40	1. 25	. 85	27. 60–41. 25	2. 05–2. 55	29. 65–43. 80	7. 5–11. 0
Sweetpotatoes	830	10. 50–15. 75	18. 60–29. 40	1. 25	. 85	31. 20–47. 25	2. 05–2. 55	33. 25–49. 80	4. 0– 6. 0

See footnotes on next page.

TABLE 20.—*Labor cost per dry pound in vegetable dehydration plants handling 50 tons per day, unprepared basis*—Continued

[1] Average hourly output per 24-hour day.

[2] Assumed hourly labor rates: Men, 75 cents; women, 60 cents; foreman, $1.25; forewoman, 85 cents. Number of employees taken from table 18.

[3] Indirect labor is estimated as follows:

Since this indirect labor charge will be applicable to 3 shifts the approximate cost to each hour's output will be ⅓, or $2.05 to $2.55.

Position	Number of employees (1 shift per day)	Cost per hour
Bookkeepers	1 or 2	$0.75–$1.50
Stenographer	1	.65
Payroll clerk	1 or 2	.75– 1.50
Superintendent	1	1.50
Field man	1	1.25
Plant chemist	1	1.25
Total	6 to 8	6.15– 7.65

Other direct and overhead costs have not been included in this calculation. Some operators believe that total overhead costs should not average more than 50 percent of direct labor, while others say that these costs may be equal to or even greater than the cost of direct labor. Still others believe that overhead costs have no relation to labor and cannot be accurately estimated on a labor basis. Wide variations occur from plant to plant because overhead costs in vegetable dehydration depend on such factors as the length of the operating season, cost of buildings and equipment, local conditions, and managerial policies. The complexity of these interrelated factors is such that no general estimates of overhead costs have been attempted.

The cost figures, although not complete, are useful guides within the indicated limits. A prospective operator can combine these figures with data specifically related to his proposed operation and thus more accurately estimate what his costs are likely to be.

The figures are based upon continuous operation which is rarely experienced in commercial plants. Where operations are interrupted or discontinuous, suitable corrections must be applied. It is apparent, also, that the cost estimates must be adjusted in any particular situation according to labor rates, shrinkage ratios, and operating procedures.

HANDLING SPECIFIC VEGETABLE AND FRUIT CROPS

Vegetables

In the following pages information is presented on the dehydration of specific vegetables. The process and to some extent the equipment required in dehydration vary with the product, and in addition the products vary in requirement for rehydration. The information that follows is more detailed for those crops that are dried in large quantities than for others. For convenience, information bearing on certain steps has been assembled in tables 21 to 26.

Table 21 shows the type of piece, blancher loadings, and time of blanching for 18 vegetables. Since it is important that the plant operator know the moisture content of the material to be used, the approximate ranges in moisture content of the vegetables are shown in table 22, together with averages. From these percentages the ratios, in weight, of water in the vegetables to "bone-dry" matter have been calculated and are shown also. Bone-dry matter must not be confused with the finshed product, which contains a low percentage of moisture, as shown by the maximum percentages permitted under Government procurement specifications. The ratio of water to dry matter in the raw product is useful to the operator, because it shows him how much water is contained in the raw commodity and makes readily calculable the weight of water that must be removed.

TABLE 21.—*Blancher loading and blanching time for specific vegetables*

Vegetable	Type of piece	Approximate blancher loading per square foot	Suggested blanching time in live steam (210°–212° F.)
		Pounds	*Minutes*
Beans, lima	Whole, shelled	1.5	[1] 5
Beans, snap	Cut	2.0	5–10
Beets	Whole		[2,5] 25–40
Beets	Cubes, slices, strips	3.0–4.0	[2,5] 2–4
Cabbage	Shreds	1.0–1.25	[3] 2–4
Carrots	Cubes, slices, strips	3.0–4.0	[2] 4–10
Celery	Slices	1.0–1.25	[3] 1–2
Chard, Swiss	Trimmed leaf	.8	[3] 2
Corn, sweet	Whole kernels on cob		4–8
Kale	Trimmed leaf	.8	[3] 2
Mustard greens	do	.8	[3] 2
Onions	Shreds, slices	1.25	[4] 1–1.5
Parsnips	Cubes, slices, strips	3.0–4.0	[2] 6–10
Peas, green	Whole, shelled	1.5	5
Potatoes	Cubes, slices, strips	4.0	[2] 2–10
Potatoes, riced	Quartered		20–25
Do	Sliced	4.0	6–10
Rutabagas	Cubes, slices, strips	3.0–4.0	[2,5] 5–10
Spinach	Trimmed leaf	.8	[3] 2
Sweetpotatoes	Cubes, slices, strips	3.0–4.0	[2,6] 6–10
Tomatoes	Slices	1	2–3

[1] Large-seeded lima beans may require 1 to 2 minutes longer for proper blanching.
[2] Government specifications require blanching until the peroxidase system is inactivated.
[3] Government specifications require blanching until the catalase system is inactivated.
[4] Government specifications do not require blanching of onions.
[5] As the peroxidase test is interpreted at present, it is usually impossible to destroy the peroxidase system in rutabagas and beets in less than 30 minutes, but if blanched as suggested above, the dried products will probably keep well in storage.
[6] Sweetpotatoes should not be permitted to come in contact with iron during blanching.

TABLE 22.—*Moisture contents of fresh and dehydrated vegetables*

Vegetable	Approximate moisture content of fresh vegetable [1]		Ratio of moisture content to bone-dry matter [1]		Maximum moisture content of dehydrated vegetable
	Range	Average	Range	Average	
	Percent	*Percent*			*Percent*
Beans, lima	58.9–71.8	66.5	1.4– 2.5	2.0	5
Beans, snap	78.8–94.0	88.9	3.7–15.6	8.0	5
Beets	82.3–94.1	87.6	4.6–15.9	7.1	[2] 5
Cabbage	88.4–94.8	92.4	7.6–18.2	12.1	[2] 4
Carrots	83.1–91.1	88.2	4.9–10.2	7.5	[2] 5
Celery	89.9–95.2	93.7	8.9–19.8	14.9	[2] 4
Chard, Swiss	89.9–92.9	91.0	8.9–13.1	10.1 [3](10.8)	4
Corn, sweet	61.3–86.1	73.9	1.6– 6.2	2.8	5
Kale	81.4–91.2	86.6	4.4– 9.3	6.5	4
Mustard greens	86.7–95.7	92.2	6.5–22.2	11.8 [3](12.2)	4
Onions	70.2–95.2	87.5	2.5–19.8	7.0 [3](8.8)	[2] 4
Parsnips	72.6–89.2	78.6	2.6– 8.3	3.7	[2] 7
Peas, green	56.7–84.1	74.3	1.3– 5.3	2.9	5
Potatoes [4]	66.0–85.2	77.8	1.9– 5.8	3.5 [3](4.0)	[2,4] 7
Do [5]					[2,5] 8
Rutabagas	86.1–91.8	89.1	6.2–11.2	8.2	[2] 5
Spinach	89.0–95.0	92.7	8.1–19.0	12.7	4
Sweetpotatoes	58.5–82.7	68.5	1.4– 4.8	2.2 [3](3.0)	[2] 7
Tomatoes	90.6–96.7	94.1	9.6–29.3	15.9	5

[1] Calculated from data of Chatfield and Adams (*10*).
[2] According to Government procurement specifications.
[3] Data in parentheses obtained at the Western Regional Research Laboratory, Albany, Calif.
[4] Cut.
[5] Riced.

The drying ratio and its converse, the drying yield, are shown for 18 vegetables in table 23. These ratios and yields have been calculated from the changes in the moisture content during the drying step. The drying ratio is the ratio of the weight of the material entering the dehydrator to the weight as it leaves the dehydrator commercially dry. The drying yield is the converse of the drying ratio and is expressed in percentage. These ratios are useful to designers of dehydrators, to operators, and also to prospective operators who wish to compare yields of product from various types of raw materials, since it can usually be assumed that the moisture content of the blanched, prepared material is approximately the same as that of the raw material.

TABLE 23.—*Drying ratios and drying yields for specific vegetables* [1]

Vegetable	Drying ratio [2]		Drying yield [3]	
	Range	Average	Range	Average
			Percent	*Percent*
Beans, lima	2.3–3.3	2.8	29.6–43.2	35.2
Beans, snap	4.4–15.8	8.5	6.3–22.3	11.6
Beets	5.3–16.1	7.6	6.2–18.6	13.0
Cabbage	8.2–18.4	12.6	5.4–12.0	7.9
Carrots	5.6–10.6	8.0	9.3–17.7	12.4
Celery	9.5–20.0	15.2	5.0–9.8	6.5
Chard, Swiss	9.5–13.5	10.6 [4] (11.3)	7.3–10.5	9.3 [4] (8.8)
Corn, sweet	2.4–6.8	3.6	14.6–40.7	27.4
Kale	5.1–9.7	7.1	10.2–19.6	13.9
Mustard greens	7.2–22.3	12.3 [4] (12.6)	4.4–13.8	8.1 [4] (7.9)
Onions	3.2–20.0	7.6 [4] (9.4)	5.0–31.0	13.0 [4] (10.6)
Parsnips	3.4–8.7	4.4	11.3–28.8	22.5
Peas, green	2.1–5.9	3.6	16.7–45.5	27.0
Potatoes	2.7–6.3	4.2 [4] (4.7)	15.7–36.0	23.6 [4] (21.3)
Rutabagas	6.8–11.5	8.7	8.6–14.6	11.4
Spinach	8.7–19.2	13.1	5.2–11.4	7.6
Sweetpotatoes	2.2–5.3	2.9 [4] (3.7)	18.6–44.6	33.8 [4] (26.7)
Tomatoes	10.1–28.7	16.1	3.4–9.4	6.2

[1] Calculated from data in table 22.

[2] Drying ratio=weight of prepared, blanched material entering drier divided by weight of dried material leaving drier.

[3] Drying yield=weight of dried material leaving drier divided by weight of prepared, blanched material entering drier x 100.

[4] Data in parentheses obtained at the Western Regional Research Laboratory, Albany, Calif.

The operator is more directly interested in the overall shrinkage ratio—that is, the weight of unprepared raw product required to yield one weight unit of finished product which meets specifications. This may also be expressed as the reversed ratio, usually as a percentage, and is then known as the overall yield. The overall shrinkage ratio is always substantially higher than the drying ratio, and the overall yield lower than the drying yield, because all weight losses incurred at various steps of the process, such as culling, washing, peeling, trimming, and inspecting, must be discounted. Estimates of such losses are presented in the discussion of certain vegetables but it must be remembered that these losses vary widely.

Suggested tray loadings are shown in table 24 for various systems of air flow. These loadings cannot be regarded as specific recommendations; instead they are to be regarded as suitable for trial. Experience with various materials will indicate necessary modifications. Loadings for cross circulation and through circulation of air are listed separately.

TABLE 24.—*Dehydrator-tray loadings suggested for specific vegetables and different systems of air flow*

Vegetable	Type of piece	Cross circulation of air per square foot	Through circulation of air per square foot
		Pounds	*Pounds*
Beans, lima	Whole	1.5	3-4
Beans, snap	Cut	1.5	6-12
Beets	Cubes	1.3-1.8	6-12
	Slices	1.3-1.5	2-3
	Strips	1.5	6-12
Cabbage	Shreds	.75-1.3	6-8
Carrots	Cubes	1.3-1.8	6-12
	Slices	1.0-1.3	2-3
	Strips	1.2-1.5	6-12
Celery	Slices	1.0-1.5	6-12
Chard, Swiss	Trimmed leaf	.75-1.3	3-6
Corn, sweet	Whole kernel	1.5-1.8	3-4
Kale	Same as for Swiss chard		
Mustard greens	do		
Onions	Slices, shreds	1.0-1.3	6-8
Parsnips	Same as for beets		
Peas, green	Same as for lima beans		
Potatoes	Cubes	1.3-1.8	6-12
	Slices	1.0-1.3	2-3
	Strips	1.2-1.5	6-12
	Riced	1.0	
Rutabagas	Same as for carrots		
Spinach	Same as for Swiss chard		
Sweetpotatoes	Cubes	1.3-1.8	6-12
	Slices	1.0-1.3	2-3
	Strips	1.5	6-12
	Riced	1.0	2-3
Tomatoes	Slices	1.3-1.8	2-3

When a bin drier is used for finishing the dehydration of vegetables, the most suitable depth of loading will vary from 2 to 6 feet and must be determined by trial. Loading depths of not over 3 feet are suggested for cabbage, sweet corn, and tomatoes. The air entering the bin finishing drier should have a dry-bulb temperature of 120°–130° F. and a relative humidity of 10 percent or less. (See p. 107.)

Variations between varieties and within a single variety due to maturity, cultural conditions, or storage conditions make it necessary to determine safe operating temperatures by trial. The general principle to be followed is that the finishing temperature shall be carried as high as possible without damage to the product. To serve as a guide the temperature conditions for different systems of dehydration are shown in table 25 for various commonly used types of drying equipment. Types of equipment and their operation are discussed in previous sections of this manual. For some of the vegetables, information is included on storage of the dried product after it has been packaged. Table 26 contains the weights of certain dehydrated vegetables that can be packaged in standard containers.

TABLE 25.—*Temperature conditions suggested in the dehydration of specific vegetables in 3 types of driers*

[Cool-end and wet-bulb temperatures should not exceed the temperatures indicated]

Vegetable	Truck and tunnel driers—				Conveyor-type drier—through circulation—						Cabinet drier—			
	Parallel-flow predrying tunnel—also primary section of center-exhaust tunnel			Counterflow tunnel used with or without predrier—also secondary section of center-exhaust tunnel	First section		Second section		Finishing end		Starting temperature		Finishing temperature	
	Hot end	Cool end	Wet bulb [1]	Hot end [2]	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb	Dry bulb	Wet bulb
	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
Beans, lima	180	160	110	150	180	110	160	100	150	90	180	110	150	90
Beans, snap	180	160	110	150	180	110	160	100	150	90	180	110	150	90
Beets	200	160	120	150	200	120	160	100	150	90	200	120	150	90
Cabbage	180	150	110	135	180	110	150	95	135–145	85–90	165	100	135	80
Carrots	200	170	120	150–160	200	120	170	105	155–160	95–100	200	120	155	90
Celery	180	160	110	125–135	180	110	160	100	125–135	90	165	100	125	80
Chard, Swiss	200	180	120	170	200	120	180	110	170	100	200	120	170	100
Corn, sweet	180	165	110	165	180	110	170	105	165	95	180	110	165	95
Kale	200	180	120	170	200	120	180	110	170	100	200	120	170	100
Mustard greens	200	180	120	170	200	120	180	110	170	100	200	120	170	100
Onions	165	145	100	[3] 130–140	165	100	145	95	130–140	85–90	165	100	130	80
Parsnips	200	170	120	155–160	200	120	170	105	155–160	95–100	200	120	160	95
Peas, green	180	160	110	150	180	110	160	100	150	90	180	110	150	90
Potatoes	200–220	160	120	145–155	180–200	120	160	100	150	90	200	120	150	90–95
Rutabagas	200	170	120	150–155	200	120	170	105	150–155	95–100	200	120	150	90
Spinach	200	180	120	170	200	120	180	110	170	100	200	120	170	100
Sweetpotatoes	200–220	170	120	160	180–200	120	170	105	160	95	200	120	160	95
Tomatoes	200	165	120	150	200	120	165	105	150	90	200	120	150	90

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[1] The wet-bulb depression at the cool end should be at least 30° F.

[2] For wet-bulb-temperatures see column 10 of figures. The wet-bulb depression at the cool end should be at least 25° F.

[3] Varies with variety.

TABLE 26.—*Weights of specific dehydrated vegetables required to fill a case consisting of two 5-gallon cans*[1]

Vegetable	Form	Net weight per case of 2 cans (5 gallons each)
		Pounds
Beets	Slices	20
Do	Cubes	34
Cabbage	Shreds	10–14
Carrots	Cubes	35
Do	Slices	25–26
Celery	Ground	40–50
Onions	Slices	18–26
Do	Powder	40–50
Potatoes	Cubes	30–31
Do	Slices	18
Do	Strips	20–30
Do	Riced	34
Rutabagas	Cubes	30
Do	Slices	25
Sweetpotatoes	do	24
Do	Riced	35

[1] 5-gallon cartons are cased individually, and the weight per carton is half the weight per case of 2 cans. Standard loadings have not been established.

In preliminary experiments, tests on the dried material aid in selecting the best operating conditions. The object of rehydration tests is to find the best conditions for preparing the product, and the object of quality tests is to place an estimate on the acceptability or desirability of the reconstituted product. In experimental work in which types, varieties, extent of blanching, and any of the other numerous factors that vary, or can be varied, are being tested, the rehydration and quality tests must supply the final measure of success or failure. In the discussion of specific vegetables which follows, the time of either soaking or boiling, or of both soaking and boiling, and the approximate drained weight of rehydrated product that have yielded the most desirable final product are frequently presented. In addition, general standards of high quality are mentioned. The procedures for making the tests are discussed in previous sections. Directions for color testing are not presented, but those operators who wish to maintain uniformity of color will find it convenient to use standard color charts, such as Maerz and Paul's (*29*) or Munsell's (*35*); thus permanent records of color of product can be made.

LIMA BEANS

Most of the commercial production of lima beans is located along the Atlantic seaboard. They require a growing season of about 4 months and fairly high temperature, and are planted later than snap beans in the Northern States. In 1942 the average yield per acre in States that produce green lima beans was about a half ton on the shelled and a ton on the unshelled basis. The dwarf or bush type is most commonly used in commercial canning and freezing, and for dehydration this type is probably better than the pole type because it can be harvested mechanically. In the North, Henderson, Fordhook, and Burpee are the common bush lima beans. Siebert, King of the Garden, and Large Green Seeded are the popular pole varieties.

In the South, Henderson bush lima and the Sieva or Carolina pole lima are commonly grown.

Ordinarily, green lima beans are vined by machine in the harvest fields. After they are vined they are mixed with cracked or crushed ice and packed in lug boxes. The safest method of handling is to process them as soon as possible. Delay should not exceed 8 hours. The shelled beans should not be held in water; this treatment may cause undesirable odors and flavors in the product.

The operations required in the preparation of lima beans are cleaning, sorting out of overmature white beans, washing, and blanching. Green lima beans are blanched in live steam for at least 5 minutes. The large-seeded types, such as Fordhook, may require 1 or 2 minutes longer. The approximate blancher-loading and blanching time are shown in table 21. If there is any delay between blanching and dehydration, the product should be cooled in water at 65° to 70° F. The delay period between blanching and dehydration should not exceed 1 hour. Information on the moisture content of shelled lima beans and on dehydrated limas can be found in table 22. The drying ratio and drying yield are presented in table 23, and tables 24 and 25 contain information on dehydration.

Dehydrated green lima beans present no unusual problem so far as packaging and storage of finished product are concerned. In rehydrating green lima beans it is recommended that 8 parts of water by weight be added to 1 part of the dried material and boiled gently for 30 minutes. At the end of 30 minutes the beans should be drained through an 8-mesh strainer and weighed. The weight of drained beans should be approximately three to four times the weight of the dried vegetable. The odor, flavor, and color should be those of freshly cooked lima beans. The texture should be soft and tender.

SNAP BEANS

Snap beans are an important vegetable crop and rank fourth among those that are canned commercially. Nearly half of the 462,000-ton commercial crop produced in 1942 was processed. The leading States in production for processing are New York, Oregon, Maryland, Arkansas, Wisconsin, and Michigan. Florida leads in production for the fresh-vegetable market. An early fall crop is harvested in Florida and harvesting continues with the early- and late-spring crops in the southern States. Summer crops are harvested in the States farther north. In California the early crops are harvested during the months of April, May, June, and July, and the late crops during the months of August and September. The average yield in Oregon, where the entire commercial production was used for processing, was 5.3 tons per acre in 1942, which was higher than that of any other State in that year. The average yield in Pennsylvania the same year was 2.85 tons per acre for snap beans grown for the fresh-vegetable market and 2.10 tons per acre for snap beans grown for processing.

Only about one-seventh of the commercially grown snap beans are produced on pole-type vines; the remainder are produced on the dwarf, or bush, vines. Almost 90 percent of the total are green beans; the remainder are yellow or wax beans. Recommended varieties of green bush beans for dehydration are Asgrow Stringless Green Pod and Dwarf Horticultural; Bountiful and Stringless Black Valentine are acceptable but inferior to the two just named. A recommended pole variety is Lazy Wife. Stringless Kidney Wax is a recommended wax bean of the bush type. Varieties of snap beans are numerous, and it is probable that other high-yielding, excellent-quality varieties are suitable for dehydration.

Harvested beans should be handled in well-ventilated packages, such as hampers, with ample circulation of air between them. There should be as little delay as possible between harvest and processing. Beans should be free from surface moisture if they are to be held more than 1 day before processing; they cannot be iced because ice might cause water-soaked areas that resemble freezing injury.

Quality is important. Snap beans should be picked when the seeds make up 10 to 20 percent of the weight of the entire pod. They should be graded closely for stage of maturity, in order to insure a uniform dehydrated product. After they are graded and sorted, the beans are snipped mechanically and then washed thoroughly. Snap beans should be blanched immediately after they are washed. (See table 21 for information on blanching.) To stop the blanching action, it is advisable to spray the blanched beans with cold water and thus reduce the temperature to 65° to 70° F. This is especially important in case of delay following blanching, which should never exceed 1 hour.

Information on the moisture content of fresh snap beans and also the dried product can be found in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration.

Dehydrated snap beans present no unusual problems so far as packaging and storage of the finished product are concerned. In rehydrating snap beans it is recommended that 8 parts by weight of water be added to 1 part of dried product, which should soak for 4 hours. After the period of soaking, the beans should be boiled slowly for 30 minutes and then drained through an 8-mesh strainer and weighed. The weight of drained beans should be approximately two to three times the weight of the dried vegetable. The product should be tender, green in color, and similar in flavor to cut fresh beans.

BEETS

Beets are a widely grown, hardy, cool-season crop. High temperature during growth adversely affects their color and texture. Since beets of deep uniform color are most suitable for dehydration, the fall crop is probably more suitable than the crop grown in the spring. The fall crop is generally used for canning and beets for this purpose are raised in the cool districts of New York, Wisconsin, Oregon, and Michigan. About two-thirds of the national crop is processed. Beets for the early fresh-vegetable market are grown extensively in Texas, and for later market in New Jersey and Pennsylvania. The varieties that are solid, or nearly solid, dark-red or reddish-purple color, such as Detroit Dark Red, Morse Detroit, and Ohio Canner, are considered best for both canning and dehydration. When such beets are dried, the color deepens toward purplish black and the lighter zones become nearly indistinguishable. Varieties with pronounced light and dark zones in the roots are not considered desirable.

Beets should be harvested before they begin to develop woodiness. They should be topped before they are stored and should be sound and free from injury. They should be stored in an atmosphere of high humidity, 95 to 98 percent, and at a temperature of 32° F. Late beets of high quality will keep from 1 to 3 months under these conditions. Prior to storage the beets should be washed, and storage time should be as short as possible. Ventilated containers, such as crates, are preferable for storage.

Grading to various sizes will effect considerable saving in waste during the peeling operation. Peeling losses will run as high as 30 percent with field-run beets; grading will reduce the loss to as low as 13 percent.

Beets can be blanched either whole or after they have been cut into slices, cubes, or strips. Blanching time will vary with size of beets or pieces and with characteristics of the particular lot, and must be continued, according to present Government specifications, until the peroxidase system is inactivated (table 21). After whole beets have been blanched they are peeled, trimmed, and then cut. There should be no delay between blanching and dehydration, but if delay is unavoidable the material should be cooled by a water spray.

Information on the moisture content of beets and on the maximum moisture content permitted by Government specifications for dehydrated beets can be found in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration, and table 26 on packaging.

In rehydrating diced beets, it is recommended that 15 parts of water by weight be added to 1 part of beets and boiled gently for 30 minutes. Longer boiling may cause deterioration in flavor and color. At the end of this period the diced beets are drained by means of an 8-mesh strainer and weighed. The weight of drained beets should be approximately 5 to 8 times the original weight of the vegetable.

Dehydrated beet slices are treated in the same manner as diced beets; the drained weight will be four to five times the original weight. The rehydrated product should be soft and tender in texture and mildly sweet. The color should be a uniform deep red and the odor should be that of cooked fresh beets.

CABBAGE

Cabbage is widely grown, with heavy concentrations in New York, Texas, Wisconsin, Florida, California, and Pennsylvania, in the order named. Of the 1.4 million tons of cabbage produced in 1942, these six States grew approximately four-fifths. The northern States, which produce the late crop, supply nearly all of the cabbage used in sauerkraut. Approximately 15 percent of the yearly cabbage crop is used for this purpose. The average yield in States that produce late cabbage was 10 tons per acre in 1942, as compared with 7.6 tons for all cabbage-growing States. The harvest in the late States generally starts about June and continues until November. The winter and spring crops in the southern States are harvested from November to May.

The Savoy variety, a green-leaved, loose-headed type, has an attractive appearance and good flavor when dried, and a higher vitamin content than the solid-head, white types, but is not grown extensively in this country because of low yields. Midseason varieties are the late strains of Copenhagen Market and its wilt-resistant strain, Marion Market; All-Seasons and its wilt-resistant strain, Wisconsin All-Seasons; and Glory of Enkhuizen. All of these are grown for the midseason market and especially for kraut making. At present it is not definitely known how these varieties compare for drying purposes. Danish Ballhead and Wisconsin Hollander are the most important varieties grown for the late market and for storage, but not for kraut. Varieties of the Danish, domestic, and pointed-head types are satisfactory for drying also, but may turn yellow upon dehydration unless special care is taken during blanching and drying. In general, they require less blanching and lower drying temperature than the Savoy varieties.

Cabbage is usually stored at low temperature range, maintained by ventilation with cold outside air. The storage house must be insulated to retard passage of heat through walls and roof, and it must be well ventilated to carry away the large amount of heat and moisture given off by the cabbage. Many of such storage houses can be found in New York, Pennsylvania, Michigan, and Wisconsin. The cabbage is stored in bins, usually made with slatted floors and solid partitions, and often several tiers high, one bin above the other. The best method of storage is on slat shelves with the heads one or two layers high, but the expense of this method may be prohibitive. Cold storage is too costly for this crop. The ideal storage conditions are 32° F. with 90 to 95 percent humidity. Late-crop cabbage will keep 3 to 4 months if properly stored. The longest-keeping varieties belong to the Danish Ballhead class. Early cabbage does not keep more than 3 to 6 weeks at 32° F.

Cabbage is usually handled in bulk or crates, the former method being most common. Since the outer leaves are relatively high in color and nutritive value, unnecessary stripping should be avoided. Trimming consists of removal of the outer bruised and discolored leaves, and waste will range approximately from 15 to 37 percent. After trimming, the core is removed with rotary cutters especially designed for this purpose or by subdividing the head with a knife in such a way as to cut out the core. (See p. 31.)

The cabbage is next washed by strong sprays of water in order to clean out the dirt and grit. By means of a rotary cutter, it is coarsely shredded into pieces not less than one-eighth inch nor more than one-fourth inch wide. Shreds that are too fine will collapse during blanching and if dried in this condition, the material will stick to the loading surface and require a longer drying time.

Prior to blanching, cabbage shreds should be washed with sprays of clean water. Since cut leaves lose ascorbic acid content rapidly, it is necessary that the material be blanched immediately after shredding. If this cannot be done, the cut leaves must be held in a 1-percent salt solution. Under no condition should the cut cabbage be held for more than 1 hour between cutting and blanching.

The product must be blanched in live steam until the temperature throughout is not less than 190° F., or until the catalase system is destroyed. This may require 2 to 4 minutes or more as shown in table 21. An undesirable color will develop in the finished product if it is overblanched. If a delay occurs between blanching and dehydration, it will be necessary to cool the product to 65° or 70° F. by means of cold-water sprays; otherwise the color of the finished product may be injured. The blanched product should not be held longer than 1 hour before being dried.

Information on the moisture content of cabbage and on the maximum moisture content permitted by Government specifications for dried cabbage can be found in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration, and table 26 on container requirements.

Hot packing of dehydrated cabbage tends to preserve the size of flakes by lessening breakage, because the dried shreds are more pliable when hot. The packaged product requires protection from both moisture and air. To meet Government specifications, the air in cans must be displaced (type 1, p. 123). The vacuum-chamber-and-pump method of removing air is recommended, and it is preferable that the vacuum chamber be equipped with a sealing head; reduction below 2 percent of oxygen would make this type of equipment necessary. The reasons for a maximum of 2 percent of oxygen are urgent. The purpose of air displacement is to save the flavor, color, and ascorbic acid by the elimination of oxygen. Analysis should be made at least 12 hours after the cans are filled and sealed.

In commercial practice, removal of air by displacement with carbon dioxide from a cylinder without a meter has produced irregular results, ranging from 1.5 to 8 percent of oxygen in the gas left in the filled can. Records obtained with an inexpensive iron-case gas meter have shown that 1 cubic foot of carbon dioxide will reduce the oxygen content of gas in the filled can to 1.8–2.4 percent in 10 seconds or 1.2–1.6 percent in 30 seconds; 2 cubic feet will reduce it to 0.8–1.0 percent in 60 seconds.

In general dehydrated cabbage is one of the less stable of the dehydrated vegetables. In storage tests Savoy cabbage that was blanched in steam, dried to 3.7 percent moisture content, and stored in carbon dioxide or nitrogen at 90° F. became inedible within 16 weeks. At temperatures of 70° to 80°, four varieties blanched and dried to below 3 percent moisture content retained both palatability and ascorbic acid without material loss. Tests with varied moisture content have shown that palatability and ascorbic acid are retained better at low than at higher moisture content.

In rehydrating dried cabbage it is best to subject it to a moderately long soaking, followed by a relatively short boiling or cooking period. When the material is to be used raw as salad or cole slaw, slightly longer soaking may be required. In rehydrating samples for testing, add 1 part by weight of dried cabbage to a consistent weight of water (10 to 15 parts). Soak for 1 hour; then simmer for 10 to 20 minutes in the same water. Drain through an 8-mesh strainer and weigh. The drained weight will be approximately 8 to 12 times the original weight of vegetable. Longer soaking will give a plumper product and slightly greater weight. Longer boiling may cause deterioration in flavor and color.

In preparing directions for use in homes and institutions, the producer should determine the amount of water and the soaking and boiling times necessary to yield a moist cooked product without excess water. A large part of the ascorbic acid will be lost if excess water is discarded. Cabbage is one of the best sources of ascorbic acid in the diet. While much is lost in the dehydration process, tests have shown that freshly dehydrated material contains 300 to 400 milligrams per 100 grams of dry cabbage.

Recently considerable interest has developed in a sulfite treatment in the dehydration of cabbage. Evidence has shown that this treatment is desirable for several reasons. (See section on "Sulfuring Vegetables," p. 42.)

CARROTS

Since carrots require a long growing season, their production is confined to areas with long periods of mild weather. Like potatoes and sweetpotatoes, carrots can be stored and are available in the fresh state the entire year; hence they are not canned in large quantities. In 1942 the California production of carrots was almost 40 percent of the total national commercial crop of 506,000 tons. Texas, New York, and Arizona rank next in production. In most carrot-growing States, the crop is harvested from late spring to late fall. In California, carrots are grown during the entire year. In Arizona, Louisiana, and Texas they are grown from late fall to early summer.

In carrots intended for dehydration, a deep uniform color, with as little difference as possible in character and depth of color between cortex and core, is a major requirement. Good to high quality and ability to stand up well under storage are also necessary. Red Core Chantenay combines desirable field and storage characteristics with deep-orange color throughout the root, and is the variety chiefly used by canners and dehydrators in the East. Nantes also has rather uniformly deep-orange flesh and high quality. Three varieties having fairly deep-orange flesh with somewhat lighter yellow cores are Imperator, Danvers, and Long Orange. Imperator is grown chiefly in the West and Southwest for shipment, and has been reported as satisfactory for drying in California.

Stage of maturity is highly important. Depth of color increases with age, but toughness and woodiness also appear and become pronounced in old material, which is hard and woody when cooked. The stage at which carrots are ordinarily harvested for storage represents the upper limit of maturity for dehydration.

Carrots are stored in fairly large quantities during the winter in those sections where the storage temperature can be held sufficiently low. They are sometimes held in cold storage, although prices do not usually justify this kind of treatment. Very light freezing may cause practically no injury, but carrots should be protected from severe freezing and are best stored at a temperature of 32° F. They are subject to wilting if the relative humidity is not 95 percent or higher; for this reason they are more easily kept in well-ventilated cellar or bank storage than above ground.

Before being placed in storage, carrots should be topped and all misshapen or injured roots sorted out. They should be kept in slat crates or ventilated barrels, and provision should be made for air circulation between the containers. Under good conditions they should keep 4 to 5 months. Washing is essential. Usually the roots are covered with mud, which increases loss due to mold and decay.

Grading to size reduces peeling waste. After grading, peeling can be done by passing the carrots through a lye, an abrasive, or a flame peeler. Waste may run as high as 24 percent for abrasive peeling. Trimming is required to remove green ends and spots along the sides. Aggregate losses from peeling and trimming will vary between 20 and 30 percent. Dehydrated carrots are either sliced, cubed, or stripped. (See table 21.) Information on the moisture content of carrots and on the maximum moisture content permitted by Government specifications for dehydrated carrots can be found in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration, and table 26 on packaging.

Dehydrated carrots require the same protection as cabbage; that is, they must be packaged in cans in which an inert gas has been substituted for air (type 1, p. 23). The method is described under Cabbage.

Dried carrots are intermediate in stability among dried vegetables. When stored at 90° F. in contact with carbon dioxide or nitrogen, samples of blanched dehydrated carrots containing 6 to 7 percent moisture were edible but of poor quality after 32 weeks. After 64 weeks they had deteriorated further but were still edible. The carotene content of dried carrots is adversely affected by oxygen in storage but is not affected by variation in moisture content.

In rehydrating dried carrots it is recommended that 8 parts by weight of water be added to 1 part of dried vegetable and boiled gently for 10 minutes if diced or stripped, and for 20 minutes if sliced. After boiling, the carrots are drained carefully through an 8-mesh strainer and weighed. The rehydrated weight should be approximately four to five times the original weight for sliced, five to six times for diced, and six to seven times for stripped carrots. Longer soaking will give a plumper product and slightly greater drained weight, but longer boiling may cause deterioration in taste, flavor, and color.

Reconstituted carrots should be mildly sweet, free from sour or bitter taste, mild in fresh carrot flavor, and soft and tender in texture. The color should be a uniform, brilliant, yellowish red. The odor should be that of cooked fresh carrots, free from the so-called violet scent.

CELERY

Celery is a cool-season crop, adapted to winter culture in the lower South and to growing either as an early-spring or late-fall crop in the central States. Farther north, in certain favorable locations, it can be grown throughout the summer. The localized distribution of this crop is due mostly to its soil requirements. Celery is grown on peat or muck, except in the irrigated areas in the West. The labor requirements for growing this crop are comparatively high. In California and central Florida, celery is produced in important quantities in the fall, winter, and spring. Midseason and late-summer crops are grown mainly on the muck soils of Michigan, New York, New Jersey, and Pennsylvania, with smaller acreages on the irrigated lands of the

Pacific Northwest. California, Florida, Michigan, and New York grew approximately 85 percent of the 1942 commercial celery crop in the United States. The late-spring celery in California yielded about 25 tons to the acre, as compared with an average of 15 tons for other celery crops of the same State during that year. The average yield for all States was 14 tons per acre.

Golden Self-Blanching and Golden Plume are well adapted to early production. For storage, Easy Bleaching Green, Utah, and Giant Pascal are best. Other excellent varieties are Crispheart, Emperor, and Winter Queen. Much of the late celery grown in the Northern States, notably in Michigan and New York, is placed in storage where it can be preserved for a period of from 2 to 4 months. While in storage, celery must be kept as cool as possible without freezing. Additional requirements are adequate air circulation and high relative humidity (90 to 95 percent).

Steps in the preparation of celery for dehydration are fairly simple. The discolored parts and those affected by plant diseases are first trimmed out by hand; then the stalks are given a thorough washing. For soup mixtures, celery is finely shredded, both leaves and stalk, 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, either whole or shredded. The stalks are cut by a rotary slicer into transverse slices about one-half to three-fourths inch thick.

The method of blanching celery for dehydration is the same as for cabbage (table 21), with the exception that celery will require about 2 minutes. As is true of cabbage, present Government purchase specifications require inactivation of the catalase system. Information on the moisture content of the fresh material and on the maximum moisture content permitted by Government specifications for dehydrated celery can be found in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on suitable conditions for dehydration.

Dehydrated celery is commonly ground to make celery salt, and is also used as flakes in some soup mixes. The commercial preparations include celery leaves, stalks, and roots dried separately. Dried celery can be ground to a powder in a hammer mill, and if it is to be ground a shaker screen will be needed. Because celery is comparatively low in sugar content, the powder is not nearly so hygroscopic as are onion and garlic powders. For this reason celery salt is not likely to cake during grinding or use. Like other seasonings, dehydrated celery is packed in cans or cartons that protect it against moisture absorption and loss of aroma. It is not necessary to pack it under inert gas. For wholesale purposes in domestic trade, cartons lined with two sheets of waxed paper are suggested. Ground celery is packed at the rate of 20 to 25 pounds to a 5-gallon unit (table 26).

Rehydration tests are not feasible for leaf powder but may be desirable for the stalks. Plant operators who wish to make tests should regard pungency as a highly valuable characteristic, and texture as secondary in importance. Minimum amounts of water should be used, and the material should be soaked rather than boiled.

CHARD

Swiss chard is a type of beet that has been developed for its tops rather than its roots and resembles beets in cultivation and distribution. Chard should be handled like other greens. The whole leaves should be cooled, preferably with crushed ice, and stored at low temperature (34° to 35° F.) and high relative humidity (90 to 95 percent). A very short storage or holding period is advisable.

In the packing plant the material should be sorted and washed. All damaged and discolored leaves should be removed and the stems cut off. Trimming and sorting losses are usually about 50 percent. Blanching should continue until the catalase system is inactivated (table 21). Uniformity of loading in the blancher is important. If delay occurs following blanching, the product should be cooled immediately to approximately 65° to 70° F. by cold-water spray or immersion. As is true of other greens, the leaves are preferably dried whole. Information on approximate moisture content can be found in table 22 and on suggested drying conditions in tables 23 to 25.

Dried greens should be carefully packaged in order to minimize breakage of the brittle product. In rehydrating it is recommended that one part by weight of dried chard be added to six parts of water, soaked for 2 hours, and boiled gently for 5 minutes. At the end of the period of boiling the product should be drained by means of an 8-mesh strainer and weighed. The weight of rehydrated product should be approximately three to four times the weight of the original dried product. In quality the rehydrated chard should resemble cooked fresh chard. It should have a pleasant flavor and should be free from unattractive odor.

SWEET CORN

The principal regions where sweet corn is produced commercially are the Great Lakes States, the Middle Atlantic States, and the New England States. It is one of the major canning crops; of the 1.4 million tons produced commercially in 1942, more than 90 percent was grown for processing.

Eighty percent or more of the sweet corn used for canning and freezing is of the hybrid varieties, most of it yellow. In total volume the white hybrids are small, but in certain districts, notably Maryland and Ohio, they are important. Of the open-pollinated varieties, a few have good quality and are adapted to widely separated regions. Stage of maturity is important, the best stage being that which an experienced canner would select for canning in whole-grain style.

Sweet corn loses sweetness rapidly after harvest, but if it is cooled quickly the rapidity of the change can be reduced. Submerging the corn in tanks of ice water or passing it through a vegetable cooler flooded with ice water is an excellent cooling treatment. Corn should not be handled in bulk because of its tenderency to heat, but should be put in baskets, small bags, or crates, and stacked so as to permit air circulation. The best conditions for holding the corn while awaiting processing are a temperature of 31° to 32° F. and a relative humidity of 85 to 90 percent. Deterioration takes place so rapidly that sweet corn should not be held longer than is absolutely necessary, and certainly not more than a few hours.

Machines husk from 1½ to 2 tons of corn per hour. After the ears have been husked they are trimmed and then washed with sprays of clean water. For best results from the standpoint of preservation of flavor and prevention of excessive loss of water-soluble nutritive factors, sweet corn should be blanched on the ear in live steam until the peroxidase system has been destroyed (table 21), as shown by a test applied to a water extract of the blanched corn after the skin and cob tissues have been filtered out. After the ears have been blanched, they should be cooled to 65° or 70° F. by immersion in clean, cold, running water. The kernels are then cut from the cob. Continuous cutters are used, and as the corn comes from the cutter it can be spread immediately on the trays. The cut corn should not be washed before drying, as this will result in loss of sugar and other soluble constituents. Chaff and cob tissue can be removed by a fanning mill after the product is dried.

Information on the moisture content of fresh and dried sweet corn is given in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on suitable conditions for dehydration.

Dried sweet corn presents no unusual problem so far as packaging and storage of the finished product are concerned. In dehydrating sweet corn it is recommended that four parts of water be added to one part by weight of the dried product. Allow the material to soak for 2 hours, and then boil gently for 10 minutes. The drained weight should be approximately two to three times the weight of the dried vegetable. The product should be mild in corn flavor and soft and tender in texture. The color should be uniformly white or yellow, depending upon the original color. The odor should be that of freshly cooked corn.

Among the best varieties and hybrids for drying are: Aristogold Bantam Evergreen, Bantam Evergreen, Golden Cross Bantam, Narrow Grain Evergreen, Country Gentleman, and Silver Cross Evergreen. Among other varieties and hybrids giving a good product are: Golden Bantam, Golden Hybrid 2439, Ioana, Marcross, Spancross, Top Cross Whipple Yellow, Tristate Hybrid, Country Gentleman 19 x 24, and Narrow Grain Hybrid 26 x 15.

KALE

Kale is a cool-weather green vegetable grown as a fall crop, chiefly along the middle Atlantic coast. It is dried in much the same manner as other greens are dried and presents no special problems. (See discussion on Swiss chard and spinach.) Losses that result from trimming and sorting average about 55 to 60 percent of the original weight. Information on blanching and dehydration are included in tables 21 to 25. Methods of rehydration and testing for quality are similar to those used with other greens.

MUSTARD GREENS

The basal leaves of the mustard plant are used for greens and make an acceptable dried product. The plant requires but a short time to reach the proper stage for use. Preparation for dehydration is similar to that for other greens. (See discussion on chard, kale, and spinach.) The weight of material lost through trimming and sorting is less than for other greens and is usually about 30 to 40 percent. Information on blanching and dehydration is contained in tables 21 to 25. Dried mustard greens can be rehydrated and tested for quality by the method used for other greens.

ONIONS

The leading onion-producing area is in New York, where the 1942 commercial production was 163,000 tons. The national average yield per acre in 1942 was 7 tons, and the yield was several tons higher in areas of heavy commercial production. During the early stages of growth the temperature should be fairly cool and the moisture supply ample. In the early-producing States, the onion harvest begins in April and ends in June. The intermediate States harvest this crop during the summer months, and the late States—eastern, central, and western—from August to October. The marketing period for late onions lasts 6 or more months after the final harvest, and extends to the late spring of the following year.

In New York the most popular varieties of onions are Early Yellow Globe and Ebenezer; in Colorado, Mountain Danvers; in Texas, Yellow Bermuda. The most common fault found with dehydrated onions is their lack of pungency. The Ebenezer, Barnett, Southport Yellow Globe, White Portugal, Red Creole, White Creole, and Yellow Danvers Flat are very strong onions and make excellent dried products. The White Portugal makes an excellent dried product, but the yield of onions per acre is low. Sweet Spanish, the various Bermudas, and similar types of onions are too mild for dehydration. Some of the more pungent varieties, for example Australian Brown (Oregon Brown or Buckskin), may yield a bitter-flavored dried product under certain drying conditions, but under other conditions they make good products. Australian Brown has a high percentage of dry matter, is an excellent keeper, and could be used to extend the season of operation, but it is difficult to peel. There is considerable variation in percentage of dry matter among varieties of onions; in this respect the mild varieties are low, and the pungent varieties high.

In the northern States, onions are held in common storage during the winter months. Part of the crop in this section is cold-stored, because after March there is likelihood of sprouting. The Ebenezer, Australian Brown, Creole and various Globe varieties are the best keepers. The most important requirement in storage is controlled relative humidity, ranging from 70 to 75 percent. Higher humidities may cause root growth and decay in the form of neck rot. A temperature of 32° F. is sufficiently low to keep onions dormant and reasonably free from decay, provided they are in sound condition and well cured when stored. Good ventilation should be provided. If the onions are packed in sacks, they should be set off the floor 2 to 4 inches with space provided around each sack. Sacks are usually stacked in pairs laid crosswise, five or six sacks high, and sometimes placed on a framework of shelves to provide ample ventilation. In some districts onions are stored in slatted crates. Good storage stock can be kept 6 to 8 months.

Onions are usually received in sacks containing up to 100 pounds, and to prevent overheating are stacked until used. Handling is much more simple for this product than for most vegetables, because blanching is not required. The onions are thoroughly washed and cleaned to remove soil and foreign material; then the outer, discolored layers are removed, after which the root base and top are cut off. They should be cut mechanically into slices or shreds ranging from one-eighth to one-fourth inch thick. In pilot-plant operations, peeling and trimming losses have varied from 6 to 15 percent.

Government purchase specifications for dehydrated onions do not require blanching of the raw material (table 21). There is evidence that storage life of the dried product is prolonged by blanching but if onions are blanched they may fail to meet existing specifications, since the appearance of the blanched product is less attractive than that of the unblanched. Prolonged blanching may cause a marked loss of pungency. The cut material should not be held longer than 1 hour before blanching or dehydration. Information on the moisture content of onions and on the maximum moisture content permitted by Government specifications for dried onions is given in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration, and table 26 on packaging (see pp. 184–188).

Government specifications limit the moisture content of onion flakes and slices to 4 percent and, in practice, flakes are packed at 3.5 percent moisture content. Onion powder should have an even lower moisture content, in order to prevent lumping. Dried onions are fragile; this fact should be kept in mind during handling in order to keep the fines low. Onion powder and flakes will absorb moisture in air having a relative humidity about 25 percent and in the room where onions are ground the atmosphere must be air-conditioned to 30 percent or less for the best results. Export shipments for the armed forces are made in hermetically sealed 5-gallon, square tin cans. For domestic shipments cartons having double waxed-paper liners, or cartons made of laminated material, including a layer of lead foil, are also used.

Dehydrated onions are more sensitive to heat than are potatoes, which occupy a middle position among dried vegetables in regard to stability. Experience has shown that too high temperature or too long exposure to a lower temperature causes a brownish color.

Dried onions in both the powdered and the rehydrated flake or slice form are used largely as seasoning agents. Rehydrated flakes or slices can be used in salads or as seasoning in soups or other vegetable mixtures and in other recipes that require raw onions, or they can be stewed and seasoned as a vegetable dish. Soaking at room temperature or in a refrigerator in a minimum amount of water (enough to insure wetting of all pieces) is the most suitable method of rehydration, and a minimum of 2 hours is required. Unblanched onion pieces will take up enough water to make them turgid and crisp in that length of time. There is considerable transfer of pungent flavor to the water during soaking, and, in the producer's directions for use, the suggestion should be made that unabsorbed water be used in soup stock or meat gravy.

Rate and completeness of rehydration can be determined by soaking the product in seven to eight times its weight of water, draining, and weighing the rehydrated sample. After soaking 2 hours, properly dehydrated onion will have reached five to six times its original weight. Rehydrated onions should be crisp and succulent and should have a mildly sweet or sweet-bitter taste and a rich, pungent odor. The color should be yellowish white to light yellow. Red onions should have yellowish-white centers with bright-red outer rings. Dehydrated onions should be cooked only after rehydration, and the time of boiling should be as short as possible. White varieties are recommended for the preparation of dishes such as buttered or creamed onions.

PARSNIPS

Parsnips are of minor importance as a commercial vegetable crop; the comparatively small acreage grown apparently reflects a lack of general popularity. The relatively poor quality of dehydrated parsnips and the fact that parsnips will keep well in the ground if protected from freezing makes dehydration impractical in most cases.

In many parts of the South parsnips are planted so that they will mature during the early summer. As they require warm weather and warm soil at planting time, they are usually planted late as compared with other vegetable crops, in other parts of the country. They may be left in the ground until used, and can be stored in cellars or pits at high relative humidity, for 2 to 4 months. When dehydrated, they are prepared and processed in much the same manner as carrots. (See tables 21 to 25.) They present no unusual problems so far as packaging is concerned.

In making the rehydrating test on dried parsnips it is recommended that nine parts of water by weight be added to one part of dehydrated slices, brought to a boil rapidly, and simmered for 5 minutes. Then the sample should be drained and weighed. Other samples should be simmered for longer periods. It is probable that the optimum quality will be attained in approximately 10 minutes, and that the drained weight will be five times the original weight of dried sample. The high-quality sample will be sweet, pungent, natural in flavor, and will have a light to moderate greenish-yellow color.

GREEN PEAS

Green peas are important in both the canning and the freezing industries and are grown and processed in large quantities in the Great Lakes region, the Pacific Northwest, New York, Utah, and elsewhere. Wisconsin leads among the pea-growing States. Peas are planted early because they are essentially a cool-weather crop. Varieties differ in time required for maturity. Two types are commonly distinguished—canning and market garden. Alaska is a popular canning pea. Other prominent canning varieties are Green Admiral, Perfection, and Surprise. Thomas Laxton, Stratagem, and Tall Telephone, which are commonly used for freezing, and Tall Alderman are market-garden varieties. In general, the market-garden varieties are best suited for dehydration. An important matter is the stage of maturity; the peas should be mature, but still green and tender.

Peas are commonly vined mechanically in the field and packed in lug boxes, in which they are conveyed to the plant. They should be cooled as quickly as possible if they are to be held for more than a few hours;

the addition of crushed ice to the lug boxes is an effective method. The safest method is to process vined peas as soon after harvest as possible. They should not be held in water. If it is necessary to hold unshelled peas before processing, keep them in air having a temperature of 32° F.

Information on the moisture content of green peas is given in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on suitable conditions for dehydration. Dried peas present no unusual problem in packaging (table 26).

In rehydrating dried peas, add 1 part by weight of dried material to 6 parts of cold water and boil slowly for 10 minutes. Then drain and weigh. The weight of rehydrated peas should be about six or seven times the original weight. The rehydrated peas should be mildly sweet and their flavor and odor should resemble those of the cooked fresh product. They should be soft and tender in texture and the color should be uniformly bright yellowish-green.

POTATOES

Of all the vegetables that are dehydrated, potatoes are the most important. The demand for dehydrated potatoes exceeds that for any other vegetable; in fact, the total present demand for potatoes is almost equal to demands for all other dehydrated vegetables combined.

The national commercial production of potatoes in 1942 amounted to 11 million tons. Potatoes are grown in all States. Maine, with a production of 1.3 million tons, or 12 percent of the national total, outranked all other States. Idaho with 918,000 tons and New York with 822,000 tons were next in importance. Five other States—California, Minnesota, North Dakota, Pennsylvania, and Colorado—each produced over 500,000 tons. The entire production of these eight States was more than half the total national crop.

Potatoes are grown during all seasons in one part of the country or another. In some of the Southern States, the harvest starts early in the spring, while in southern Florida and in the lower Rio Grande Valley potatoes are harvested toward the end of the year. Early potatoes are a relatively unimportant part of the total production. The season of availability for the intermediate and late crops extends from the beginning of harvest in late summer to at least the late spring of the following year. Yields per acre are influenced to a large extent by climate and the use of irrigation. They vary widely from year to year and among the States. The 1930–39 average yield per acre for all States was 3.4 tons, compared with 3.9 tons in 1941.

For dehydration many operators prefer the type that becomes white and mealy with cooking. Experimental testing of potatoes grown in any given area, prior to the establishment of a new dehydration plant, is advisable as a means of determinating (1) the operating conditions that make the best dried product, (2) the acceptability of this product for use, and (3) the yield of dried product obtainable from the raw material.

The variety of potato most widely grown in the United States is the Irish Cobbler. Because of its remarkable adaptability, it is grown to some extent nearly everywhere. The Triumph is second in importance and acreage, with large concentrations in the Middle West, and Katahdin is the third most important variety. The Green Mountain group is important in Maine and the neighboring States. Production of the Russet Burbank group of varieties is concentrated entirely in the Northwest. In California, the White Rose is the leading variety. Rural Russet and Rural New Yorker No. 2 are grown extensively in certain States in the region of the Great Lakes. The conditions under which these varieties are grown affect their suitability for dehydration.

A variety of potato, to be suitable for dehydrating, must be grown in a district and under conditions to which it is suited, and where it will give optimum yields. Russet Burbank when grown in Idaho, for example, is excellent, but the same variety grown in Maryland, where it is not adapted, makes an inferior product. Likewise, potatoes satisfactory for dehydrating can be grown in a certain district only if varieties adapted to that district are used.

Limited tests have shown the following varieties to be among the best when grown in the States indicated:

Michigan: Rural Russet, best; Irish Cobbler, Green Mountain, Chippewa, Katahdin, and Sebago, very good.

New York: Green Mountain and Pioneer Rural best; Katahdin and Chippewa, very good.

Washington: Russet Burbank and Sebago, best.

Idaho: Russet Burbank, best; Sebago, Triumph, and Katahdin, very good.

Colorado: Triumph and Katahdin, best.

Maine: All the varieties named above produce excellent or very good stock for dehydrating.

Immaturity or other factors that result in high water content definitely impair quality for dehydration. Immature "new" potatoes are not suitable for this purpose.

Only mature tubers, free from disease and bruises, should be stored. A storage temperature of 40° F. is low enough to keep mature potatoes dormant 3 to 5 months. At this temperature, however, they may become mildly sweet. If stored at 40° or lower, the potatoes may show marked yellowing and browning at the center of the piece after being dehydrated. For short-time storage, a temperature of 50° to 60° results in good texture, color, and flavor in the cooked product. Potatoes stored at the lower temperatures should be held at 60° to 65° for 3 to 4 weeks just prior to dehydration. Under these conditions the sweet taste will be lost and a satisfactory dried product obtained. The relative humidity recommended for potato storage is 85 to 90 percent.

Potatoes are commonly stored in pits or large bins of 150 to 1,000 bushels in the Northern States, but in milder climates they should be stored in small units. Heat insulation and ample ventilation are needed to provide the best conditions for storage. Potatoes should always be stored in the dark because in the light they become green and unfit for food as a result of the development of solanine, a bitter poisonous substance. In most districts potatoes are handled and stored in bags. After delivery to the plant, measures must be taken to make sure that the crop will remain in good condition until used. An even, moderately cool temperature should be provided, in insulated rooms if necessary. The bags should be stacked so as to provide enough aeration to prevent heating. When the weather becomes cold, heat should be provided to prevent freezing. Since potato handling is almost an all-year job, maintenance of cool storage to reduce spoilage is important.

Thorough washing is the first step in the preparation of potatoes. This operation can be carried out by running them through a revolving corrugated-drum or squirrel-cage washer equipped with sprays. Following washing, grading to size should be performed if abrasion or radiant-heat peeling is used, since grading speeds up the peeling operation and reduces waste. With lye or brine peeling, grading to size is less important.

Trimming is necessary after the peeling operation to remove the eyes and black spots or unsound or damaged portions that remain after the product has passed through the peeling machines. The total waste from peeling and trimming varies with the grade and size of the tubers, the peeling method used, and the care exercised in peeling and trimming. In commercial plants this waste is rarely lower than 15 percent, and may rise to 30 or even 40 percent if the raw material is inferior or the operation is conducted carelessly. With abrasive peeling the average over-all loss is about 23 percent and the range 18 to 27 percent. With lye, brine, or heat peeling, the losses may be considerably less—as low as 12 percent.

The peeled and trimmed potatoes pass to mechanical cutters where they are cut into slices, cubes, or strips (julienne style) in accordance with the form desired. (See p. 34.)

After being cut the potatoes proceed to a washer where the loose starch is removed. This operation is then followed by blanching. If delay between cutting and blanching is unavoidable, the cut material must be held under potable cold water or a clean 2 percent salt solution. This procedure will protect the cut product from discoloration as the result of enzymatic oxidation. The prepared material should not be held for more than 1 hour before blanching. If the potatoes are to be riced, the peeled and trimmed potatoes can be quartered or sliced and then blanched. (See table 21.)

After being blanched, the material should be sprayed again with clean water in order to remove loose starch that might cause the pieces to stick together during dehydration. Delays between blanching and dehydration should be avoided. In any case, the material should not be held longer than 1 hour. Quartered potatoes that are to be riced are exposed to live steam until cooked, usually for 20 to 25 minutes. After this operation and while still hot, they are passed through a mechanical ricer directly to the drying trays.

Information on the moisture content of potatoes and on the maximum moisture content permitted by Government specifications for dehydrated potatoes is given in table 22. The drying ratio and drying yield are shown in table 23. Tables 24 and 25 contain information on dehydration. (See pp. 184–187.)

Tin cans have been replaced to some extent by 5-gallon square cartons as containers for dehydrated potatoes. Dehydrators will require between 250 and 380 five-gallon cans or cartons for every 10 tons of raw untrimmed potatoes that are to be dehydrated (table 26). Dehydrated potatoes are moderately sensitive to heat, being less susceptible than carrots and more so than sweetpotatoes. In 1921 Gore and Rutledge (*18*) reported that dried potatoes containing 6.3 to 6.6

percent moisture content did not discolor in 700 days at 35° F., discolored slowly at 75° and browned rapidly at 105°.

The color and texture of rehydrated potatoes are influenced by the variety, growing environment, maturity, predrying storage, predrying preparation procedures, time and method of blanching, drying conditions, and methods of rehydration. Under-blanched dehydrated potatoes will rehydrate slowly and incompletely. If over-blanched, the pieces may disintegrate in part or entirely when rehydrated at boiling temperatures. The most unsatisfactory samples are those that partially disintegrate, forming a mush in the water while the centers of the pieces remain dry, hard, and chewy. It is assumed that cubes, strips, and slices are produced because the forms are desired for specific table preparations; the rehydration procedure should therefore preserve these forms. Samples of high quality will be rehydrated successfully by boiling without previous soaking, but since table preparations, such as fried, escalloped, and hashed browned potatoes, are best when unboiled potatoes are used, the rate and completeness of rehydration at room temperature, as well as at the boiling point, should be determined.

Because of the great number of factors that affect quality, some of which can be overcome by changing the conditions of rehydration, it is recommended that each producer conduct a series of tests for rehydration and quality on each lot of potatoes. An acceptable product should be rehydrated to satisfactorily plump pieces without becoming mushy or watery. The rehydration ratio (the rehydrated weight divided by the dry weight) will vary with the size and shape of the piece, the time held in water, and the temperature of the water. Rehydration ratios obtained with high-quality samples are given in table 27.

TABLE 27.—*Rehydration ratios obtained with high-quality samples of dehydrated potatoes*

Form	Size	Boiled without soaking			Boiled after soaking overnight			Soaked overnight, not boiled
		5 minutes	10 minutes	20 minutes	5 minutes	10 minutes	20 minutes	
	Inch							
Cubes	6/16	2–3	3–4	3–4	3–4	3–4	4–5	2–3
Slices	2/16			4–5				
Strips	5/32	3–4	4–5		4–5	4–5		3–4

In rehydrating dried cut potatoes, add 8 parts of water to 1 part by weight of the product and boil separate samples gently for 5, 10, and 20 minutes. Drain carefully through an 8-mesh strainer for 2 minutes. The rehydrated weight should be approximately two to four times the original weight for diced or cubed, and three to five times for julienne strips. Soaking before boiling will give a plumper product and slightly greater drained weight in the larger pieces. Long boiling will cause deterioration in taste, flavor, and color. The rehydrated product should be free from sour or bitter taste, mild in potato flavor, and soft and tender in texture. The color should be uniformly yellowish white to pale yellow. The pieces should be whole and nearly perfect in form.

The addition of 5 to 7 parts of half-and-half milk and water to 1 part by weight of dried riced potatoes should yield a product having the normal consistency of mashed potatoes. If four parts of liquid yield a material thinner than is normal, the dehydrated riced potatoes may be considered unsatisfactory. The material should be held in a double boiler for 30 minutes at room temperature, placed over boiling water for 10 minutes, or until heated throughout, and then whipped until light and fluffy. The whipped material should be reasonably free from lumps and should have a mealy texture. A product having a waxy or pasty consistency should be considered unacceptable.

RUTABAGAS

Rutabagas are grown chiefly in the northern States and require 4 months or more to reach maturity. American Purple Top, Bangholm, and Early Neckless are varieties commonly used for dehydration. Harvested roots can be stored satisfactorily for several months in caves or pits at 32° to 40° F. and at high relative humidity (95 to 98 percent). Much of the commercial crop is waxed prior to storage, as a means of reducing wilting.

Preparation includes washing, peeling, trimming, and cutting. Waste in preparation ranges approximately from 8 to 15 percent. Although present Government purchase regulations specify inactivation of the peroxidase system by blanching, such inactivation requires almost half an hour in live steam, which is much longer than is necessary to obtain a dried product that will keep well in storage (table 21). Information on moisture content of fresh and dried rutabagas and on temperature and humidity conditions suggested for trial in dehydration is presented in tables 22 to 25. Information on packaging is presented in table 26.

Dried rutabagas are packaged in much the same manner as dried potatoes—that is, in 5-gallon cans or lead-foil-protected cartons. In Canada, dried rutabagas are packed in cans containing an inert-gas atmosphere. They are readily injured by high temperatures during storage. The weight of material that can be packaged in a 5-gallon can is shown in table 26.

In determining rehydration characteristics, add 8 parts of water to 1 part by weight of the dried product and boil for 30 minutes. The drained weight of rehydrated product should be approximately five to six times the weight of dried vegetable. It should have a flavor and odor similar to those of cooked fresh rutabagas and the color should range from yellow to buff.

SPINACH

Spinach is grown during the entire year, in one section or another of the country, as a late-fall, winter, spring, or summer crop. The summer and winter culture of spinach is possible only where moderate heat or moderate cold prevails. The most extensive plantings of early or winter spinach for the fresh-vegetable market are in Texas and California. Pennsylvania and New Jersey grow the bulk of the summer crop. Approximately half of the commercial crop is processed, the major portion in California.

The varieties of spinach commonly grown for use as fresh vegetable are probably satisfactory for drying. Nobel, also known as Giant Thick Leaf, is very productive. The smooth leaves are easily cleaned, and it stands for a long time before going to seed. Long Standing Bloomsdale is the most widely grown savoy-leaved variety. Virginia Savoy and Old Dominion are good varieties for fall planting, since they are hardy, but are not suited for spring planting.

Spinach is perishable and should be processed as soon as possible after harvest. Cooling quickly to 34° or 35° F. in air at 90 or 95 percent relative humidity will help prevent spoilage. Crushed ice applied to the pack will hasten cooling and protect the quality over short periods of unavoidable delay.

Undue handling or bruising of the leaves of fresh spinach will result in large losses of ascorbic acid. The first step in the preparation is the cutting off of the roots. The loose material is then washed under cold water sprays as it is loaded on the conveyor belts. Next, all damaged and discolored leaves are removed and the stems cut off. Not more than 10 percent of the stem should remain on the spinach. Trimming losses for spinach range from 45 to 65 percent. After sorting and trimming, the leaves are thoroughly washed to remove the remaining sand and dirt.

Spinach should be blanched, as soon after preparation as possible, in live steam until the catalase system is destroyed (table 21). Care must be taken to see that the leafy material is uniformly loaded in the blancher. If there is a delay between blanching and dehydration, the product should be cooled immediately to 65° or 70° F. by means of water sprays or immersion in cold water. This is essential as a means of preventing discoloration (undesirable brownish color) in the finished product. The delay between blanching and dehydration should not be more than 1 hour.

Information on dehydration is presented in tables 22 to 25. The leaves are preferably dried whole. Various kinds of greens should not be dried together, nor should they be mixed after they are dried. Because of the limp condition of the blanched leaves, care should be taken to spread the material so that it will not pile up in bunches.

Government procurement specifications require dehydrated spinach to be packaged in hermetically sealed containers in which the air has been replaced by nitrogen or carbon dioxide gas. Spinach dried to 2 percent moisture content can be packaged in lead-foil-protected cartons if it is stored at safe temperature and for short periods, such as would commonly be possible in domestic use. For longer and more severe storage, such as would be necessary in shipment abroad, gas-packed sealed cans are advisable. In quality tests, unblanched spinach dried to 2 percent moisture content and stored at 90° F. was found to retain its palatability after more than a year.

For the rehydration test the following procedure is recommended: To one part by weight of dried spinach add six parts of water. Soak for 2 hours and then boil gently for 5 minutes. The drained weight of the rehydrated product should be about three to four times the original weight. Longer soaking will do no harm, but longer boiling will cause loss of vitamins and flavor. The product should be mildly bitter, soft, tender, a uniform dark green, and free from foreign odor.

SWEETPOTATOES

Sweetpotatoes rank next to potatoes in importance as material for dehydration, and are an important crop in the South and in the Middle Atlantic States. Approximately 707,000 acres of sweetpotatoes were harvested in 1942. Georgia, with 100,000 acres, or 14 percent of the total, ranked first in acreage harvested, as well as in total production. The 1942 production of 1.8 million tons was only one-sixth as much as the potato production in that year. In the years 1930-39 the combined production of nine Southern States, which outranked all other States, averaged 1.6 million tons or 80 percent of the total. The harvesting of this crop extends from as early as June to August in Georgia, and from as late as September to November in many of the other sweetpotato-growing States. The average yield per acre for all States was 2.5 tons in 1942.

Both the moist "yam" and the so-called dry-flesh varieties are suitable for drying. The products, however, are different, and the two types should not be mixed. Numerous varieties are grown, but those that are of commercial importance are less than a dozen in number, and of these not more than four or five are of importance. Porto Rico and Nancy Hall are the chief varieties in the South. In New Jersey, Maryland, Missouri, and Kansas, members of the Jersey group—Big-Stem Jersey, Maryland Golden, Yellow Jersey, Orange Little Stem, and Vineland Bush—are of chief importance. These are not all equal in suitability for dehydration, and because of varietal differences, as well as differences in soil and climatic conditions, tests should be made prior to the establishment of a plant in a given area, to determine (1) the operating conditions that make the best dried product, (2) the acceptability of the product, and (3) the yield of dried product obtainable from the material.

Rather extensive trials have shown that Nancy Hall and Nancy Gold yield dried products of the highest quality. Porto Rico, Orange Little Stem, Maryland Golden, Big-Stem Jersey, and Yellow Jersey all gave equally good dried products very close in quality to Nancy Hall and Nancy Gold.

Sweetpotatoes require special handling to prevent loss during storage. Only well-matured stock should be used, and it should be cured for 10 to 14 days at temperatures of 80° to 85° F. with a relative humidity of 85 to 90 percent. This may necessitate the use of artificial heat. After curing, the temperature is allowed to drop to about 55° with a relative humidity of 75 to 80 percent. Short periods at temperatures of less than 50° will do no harm, but exposure to low temperatures for long periods may cause certain types of decay, frequently characterized by the formation of dark spots which may show in the raw material or develop only during the drying process. Prolonged storage of sweetpotatoes causes deterioration of the raw stock, with resulting poor quality of the finished product when dehydrated. Slatted crates, bushel baskets, or shallow bins are used for storage. The roots should be handled as little as possible while stored.

Sweetpotatoes are first washed and then steamed for 10 minutes to facilitate peeling. Following washing, grading to size should be performed if abrasion peeling is used, since grading results in considerably reduced waste. Abrasive peelers cause a heavy loss when used on either raw or steamed sweetpotatoes; the waste in peeling and trimming will run from 15 to 30 percent for sound materials. Hand, brine, or lye peeling can be used with considerable reduction in losses.

Sweetpotatoes are cut into slices, cubes, or strips. Government purchase specifications limit cubes to the three-eighths-inch dimension. Immediately after cutting, the pieces should be washed thoroughly by strong sprays of clean cold water in order to remove starch from the cut surfaces. If not blanched immediately, the cut material should be kept under running cold water or in a 2 percent salt solution. For material on which this treatment has not proved effective the use of a 1 to 2 percent citric acid solution has been recommended. Citric acid is not, however, readily available. In any case, the material should not be held for more than 1 hour before blanching.

If the sweetpotatoes are to be riced or powdered, they are precooked before they are dried. To make the riced product, the sweetpotatoes are given the same preliminary treatment as potatoes, except that instead of being cut in pieces, the whole tubers are steamed until thoroughly cooked. The cooked product is then passed through a ricing device having holes not over one-eighth inch in diameter. If the ricing is done while the potatoes are hot, there is less tendency for the strings to stick together. The strings should fall from the ricer to the drying surface.

Sweetpotatoes should be blanched as soon as possible after they are peeled and cut. Blanching in steam is recommended. The time must be adjusted to allow complete destruction of the peroxidase system, which requires 6 to 10 minutes (table 21). It is essential to avoid all contact with iron during blanching. Failure to observe this precaution will result in blackening of the product. A suggested blancher loading is shown in table 21 (p. 184). The maximum delay allowable between blanching and dehydration is 1 hour.

Information on the moisture content of fresh sweetpotatoes and on drying ratios and conditions suggested for dehydration is contained in tables 22 to 25. Table 26 contains information on packaging. Dried sweetpotatoes are considerably less affected by heat and moisture than are dried potatoes. For export 5-gallon cans or lead-foil-protected cartons, without gas packing, are used.

The rate and effectiveness of rehydration of sweetpotatoes can be determined by obtaining the drained weight of the rehydrated sample at various intervals of time and temperature in water. To obtain this drained weight add six parts of water to one part by weight of sliced sweetpotatoes and boil gently for 30 minutes. Drain carefully through an 8-mesh strainer for 2 minutes and weigh. The rehydrated weight should be approximately two or three times the original weight of the dried vegetable. Rehydrated sweetpotatoes should be sweet, free from bitter, strong, or sour taste, mild in sweetpotato flavor, and soft and tender in texture. Their color should be that of cooked fresh sweetpotatoes of the same variety, free from dark spots and streaks.

Soaking before boiling will give a plumper product and slightly greater drained weight. Longer boiling may cause deterioration in taste, flavor, and color. Products that have been stored for some time at 90° F. may absorb water more slowly than freshly dried material.

Soaking before boiling will compensate for this more satisfactorily than will increasing the time of boiling. There is a tendency toward disintegration of pieces when boiled 30 minutes, but a raw taste and flavor may result from shorter boiling.

TOMATOES

Tomatoes are widely grown and rank first among crops that are canned. They are highly nutritious and comparatively easy to produce; they yield well and are consumed in large quantities. Dehydration of tomato slices of fleshy varieties in the types of equipment used for other cut vegetables is possible, but the product is hygroscopic and does not keep well except in tightly closed cans. Tomato puree can be dried on drum driers and juice can be spray-dried to form a powder. There is considerable interest in the latter products but thus far commercial production has not been developed. Progress has been made with the technical problems of tomato dehydration, but because of the high water content of tomatoes the method is not highly feasible from the economic standpoint. Moreover, tomatoes and tomato juice can be easily preserved by canning in glass containers, of which there is an ample supply.

Fruits

The information presented here on fruits is concerned chiefly with dehydration in tunnel and cabinet dehydrators, by means of currents of heated air. Sun drying, evaporation in kilns, spray drying, vacuum drying, and other methods are also, in greater or less degree, established commercial methods of producing dried fruits or dried-fruit products, and some of these methods are also applied to vegetables. Although the chief purpose of this publication is to deal with the use of tunnels and cabinets particularly in vegetable dehydration, similar equipment is used for fruits. For technical guidance in the dehydration of fruits other sources should be consulted (*7*, *9*, *11*, *13*, *36*, *46*, *47*), and Circular 619 (*9*) gives an extensive bibliography.

Most fruits should be harvested frequently and then dried as soon after harvest as possible. Apples, apricots, cherries, peaches, pears, and nectarines should be picked from the trees and not allowed to fall to the ground. Prunes are harvested from the ground two or three times during each season. The trees are shaken for the second and third pickings. Figs are harvested from the ground and are usually one-third to two-thirds dried when harvested. Grapes are harvested from the vines by pulling or cutting off the bunches. All of the softer small fruits require special care in handling and will tolerate very little storage; such fruits are not dried commercially in large amounts. Apples, pears, and cranberries can be stored over fairly long periods; pears must be dried as they ripen in storage. Citrus fruits have the advantage of good keeping quality in storage; drying of citrus fruits, however, is still in the experimental stage.

Although high-quality fruits yield the best dried products it is a common practice to dry packing-house and cannery culls. All fruits should be carefully washed. Apples and pears can be washed at the time of spray residue removal in a continuous machine. Other fruits may be washed under sprays or by immersion while moving on a belt. Growers with small quantities commonly wash fruit in boxes by immersion. Rotary washers should not be used for tender-fleshed fruit.

Blanching is seldom used in the preparation of fruits for drying, but is advisable for apricots, nectarines, peaches, and pears if they are to be dehydrated rather than sun-dried (*34*). Prunes and some grapes are commonly dipped in hot lye solution as a means of making fine breaks in the skin; this effect, referred to as checking, facilitates drying. The treatment is not however a blanching operation—that is, a thorough penetration by heat. For the most part, large pieces or whole fruits are dried, in contrast to the thin slices, cubes, or strips of vegetables. Fruits contain large quantities of juice, and when blanching is used it must be carefully controlled to avoid excessive loss of juice, called bleeding.

Blanching in a manner similar to that used with dehydrated vegetables has been suggested for certain cut fruits that are to be dehydrated, as a means of improving quality from the standpoint of cleanliness, freedom from insects, superior vitamin retention, and better appearance. Sulfuring is, however, standard commercial pretreatment for the lighter colored fruits, such as apples, apricots, golden-bleached raisins, peaches, pears, and nectarines. Prunes and figs are very rarely sulfured. Fruit is usually sulfured in a sulfuring house while on trays stacked on trucks. The trays must be nonmetallic. The trucks occupy most of the space but there must be sufficient open space to permit free circulation of the fumes. It is advisable to burn sulfur in a shallow iron pan placed at or slightly below the floor level between the entrance and the nearest truckload of fruit. The amount of sulfur burned and time of sulfuring varies with the type and condition of the fruit (*28*, *33*). Exposure of sulfured fruit to sunlight for a few hours before it is put into the dehydrator is sometimes used as a means of improving color but this is not necessary if blanching is used.

Most of the commercial fruit dehydration industry is located along the Pacific coast. In areas where sun drying is feasible—particularly northern and central California—it is used as well as dehydration. Apricots, peaches, pears, and raisins are for the most part sun-dried. Apples are dried in large quantities in New York and Washington and cranberries are dried chiefly in New England.

Mechanical fruit driers have gone through a long period of development, and a large number of older types and designs are still in use. During the later years of World War I and in the period that followed, a number of new commercial makes of driers were introduced, chiefly of the tunnel type with forced draft. In California, where sun drying is common, the mechanical drier was originally looked upon as "rain damage insurance," and, although rains are infrequent there during the drying season, a series of rains, such as the destructive wet spell of 1918, could cause enormous losses. Size of operation and consequently size of mechanical installation varies, with capacities ranging from a few tons daily to 100 tons or more. The mechanical equipment also varies with the type of fruit; a prune drier, for example, differs in certain respects from other types. The type most generally used is the counterflow tunnel with varying methods of heating, air flow, and air propulsion. The fruit is conveyed on trays loaded on trucks.

Table 28 presents general information on fruit dehydration by mechanical methods. Because of the variation in equipment and the fact that fruits are not dried to the low moisture contents of vegetables, except in the form of nuggets and powders, the data vary considerably. As is true of vegetables, the temperature should be carried as high as possible without injury to the product. Experience and the application of principles discussed in earlier sections of this manual are necessary in practical operation.

TABLE 28.—*Preparation and dehydration of fruits* [1]

Fruit	Type of piece	Tray loading per square foot	Pretreatment [2]		Maximum finishing temperature [3]	Moisture content of product	Yield, unprepared basis
			Method	Time			
		Pounds		*Hours*	°*F.*	*Percent*	*Percent*
Apples [4]	Slices	1.5	Sulfur	½–2	155	15–20	10–15
Apricots [5]	Halves	2.0	do	1–2	155	15–20	15–20
Berries [6]	Whole	1.0–1.2			150	10–15	15–20
Cherries (pitted) [7]	do	1.0			165	24–28	15–25
Cranberries [8]	Chopped	.8–1.0			150	5–10	10–15
Figs (Kadota) [9]	Whole	3.0	Sulfur	2–3	160	15–20	25–30
Grapes [10]	do	3.5			160	15–20	20–30
Peaches	Halves	2.5	Sulfur	2–3	155	15–20	15–20
Pears [11]	do	2.5	do	3–5	150	10–15	10–20
Prunes [12]	Whole	3.0	Lye-solution dip		165	15–20	30–40
Walnuts	do				(13)		

[1] The data presented here were obtained from several sources and represent approximate commercial tunnel-drying practice. Government purchase specifications have been issued for a number of dried fruits and dried-fruit products.

[2] If feasible, sulfured fruit is often exposed to sunlight for several hours just before it is dehydrated.

[3] The starting temperature varies with the equipment and the fruit, and can be determined by trial.

[4] Apples are extensively evaporated in kiln driers. (See text.) They are commonly sulfured by immersion for 15 to 20 seconds in 0.25 percent sodium bisulfite solution.

[5] A somewhat longer sulfuring time is required for sun drying.

[6] Strawberries, raspberries, loganberries, blackberries, and others.

[7] Cherries should be dipped in sodium carbonate solution when dried whole. Royal Anne and sour cherries should be sulfured. Unpitted cherries will yield a higher percentage of dried product than that shown in the last column.

[8] Considerable amounts of drum-dried cranberry puree are produced commercially.

[9] Figs other than Kadotas are not sulfured.

[10] Light-colored grapes used to produce bleached raisins are dipped in hot lye solution to check the skins and then sulfured about 3 hours.

[11] Longer sulfuring (24 to 48 hours) is used for sun drying.

[12] Hot- or cold-water dip may be used when fruit is to be dehydrated. Lye dip is always necessary when fruit is to be sun-dried.

[13] Not over 110.

Dried fruits are usually stored in bins holding several tons, if they must be held for some time before delivery to the packer. Packers buy the dried fruits in bulk and grade, process, store, and package them for distribution. Bulk dried fruits are usually handled in boxes. For domestic consumption, dried fruits are usually packaged in paper cartons or in wood or fiber boxes. Fumigation is usually necessary, to destroy insect infestation. Most dried fruits are pressed to some extent when they are packaged.

APPLES

Apples constitute about one-fifth of all the fruit grown in the United States. Production is heavily concentrated in Washington, New York ranks second, and a number of other States produce substantial quantities.

Fresh apples can be stored for several months at 35° to 38° F. The length of storage period varies with the variety. Spray residue must be removed from apples before they are used; removal can be accomplished by means of a hydrochloric acid wash. Further preparation includes peeling, coring, trimming, slicing, and sulfuring.

The best, although not the standard, method of grading dried apples is based on quality of sauce, pie, or other product. By this method, varieties of inherently good cooking quality rank high, and such varieties are best for dehydration because all dried apples are cooked. In commercial practice, the whitest dried apples are rated highest regardless of variety. Whiteness, however, is to a considerable extent controlled by sulfuring. Late-maturing, firm-fleshed varieties are generally suitable for drying. Apples are sulfited by dipping for 15 to 20 seconds in a 0.25 percent solution of sodium bisulfite after slicing or by exposure to the fumes of burning sulfur for about 20 minutes after peeling but before slicing.

Apples are commonly dried in kilns, or evaporators. The fresh slices are spread about 18 inches deep on a slatted floor; hot air passes through the fruit, which is turned once or twice with a shovel, and the finished fruit (after about 20 hours of drying) is shoveled into bins. Apples can also be dried by mechanical, forced-air dehydration (table 28). This method is used extensively in Canada, where the center-exhaust system is advocated (*14*). Apple crisps, or nuggets, are produced by coarsely grinding evaporated apples and drying the small pieces to 3 percent moisture content or lower (Government purchase specification) by the vacuum process. This product has much better keeping quality, especially at higher temperatures, than ordinary dried apples.

APRICOTS

Commercial production of apricots is restricted to the Pacific coast, with 90 percent in California. During the years 1936–40 about 65 percent of the California crop was dried, 25 percent was canned, and 10 percent sold in the fresh state. Increasing amounts are being preserved by freezing. The production in the other States is sold for the most part on the fresh-fruit market. Almost half of the dried apricot pack is exported. The Blenheim and Royal varieties, which are indistinguishable, are preferred for drying because they bear well and the dried product is excellent in quality. Other varieties commonly dried are Tilton and Moorpark.

Fresh apricots cannot be stored more than 1 or 2 weeks, and for best dessert qualities they must be harvested when fully ripe. They are never peeled before being dried. Preparation includes washing, halving, and pitting. Trays are loaded with a single layer of halves, laid with the cups up. The fruit is then sulfured and dried in the sun. If it is to be dehydrated, it should be blanched about 3 minutes prior to sulfuring. Apricot powder is made by grinding dried apricots and drying the ground material under vacuum to a low moisture content (2½ percent for Government purchase).

BERRIES (INCLUDING CRANBERRIES)

Strawberries are produced commercially in many States, with large commercial production in Arkansas, Louisiana, and Oregon. Most of the commercial production of cranberries is located in Massachusetts, Wisconsin, and New Jersey; Washington and Oregon produce the remainder, about 10 percent of the national total. Nearly all the commercial canning and freezing of berries other than cranberries takes place in the Pacific Coast States. Berries can be dehydrated but, with the exception of cranberries, few are dehydrated commercially. Cranberries are stored in refrigerated warehouses, but usually not longer than 3 months. In the preparation of puree for drum drying, cranberries are cooked in a small amount of water until the skins crack and are then put through a pulper to remove skins and seeds. The puree is dried on a steam-heated stainless-steel drum and comes off the drum in a continuous sheet which is ready to be pulverized.

CHERRIES

Sour cherries are produced mostly in the Great Lakes region and the Eastern States, and most of the sweet cherries are grown in the Pacific Coast States. Michigan and California lead in production. Common varieties of sweet cherries are Bing, Royal Anne, and Tartarian. The leading sour cherry is Montmorency. Both sweet and sour cherries can be dehydrated but are not dried in large amounts. Fresh cherries can be stored for only a short period. In preparation for dehydration cherries are stemmed and then thoroughly washed. Pitting is done by a machine. Cherries can be dried without pitting; thus loss of juice is avoided. Steam blanching has been suggested but gives the fruit an undesirable texture. Royal Anne and sour cherries should be sulfured before they are dried.

FIGS

Figs are produced for the most part in California, but to some extent in Texas. Four varieties are dried: Calmyrna, Adriatic, Kadota, and Black Mission. The first three are light-colored and the latter black. Kadota is grown chiefly for canning and is not commonly dried. The dried Calmyrna is considered superior to the dried product of the other varieties. Figs are both sun-dried and dehydrated. They dry to a considerable extent while hanging on the tree. Most figs are dried without any pretreatment. Kadota may be sulfured. If they are to be dehydrated, exposure to the sun for 1 to 2 days is essential to remove the green color.

GRAPES

Grapes rank third in production among fruits—below apples and oranges. California leads in production; in fact, 90 percent of the total national crop is produced there. New York and Michigan rank next, and a large number of States produce minor quantities on a commercial scale. Varieties can be classified, according to use, as raisin varieties (about three-fifths of the total), wine or juice varieties, and table varieties. Raisin grapes should have a sugar content of about 23 percent. Nearly the whole national production of raisins is dried in California, where they are largely sun-dried without pretreatment, usually in the fields where they grow. Sulfur-bleached raisins are prepared by dipping seedless grapes in alkali to check the skin, sulfuring, exposing to the sun for 3 to 4 hours, and then drying in the shade. A similar preparation procedure is used for golden-bleached raisins but they are dehydrated artificially rather than sun-dried.

PEACHES

In the production of peaches, California ranks first among the States and Georgia second. In California most of the clingstone peaches are canned, whereas the larger part of the freestone crop is dried. Of the total peach crop in that State, about one-third is freestone, and the most important varieties are Elberta, Lovell, Muir, and J. H. Hale. Most of the Elberta crop is sold in the fresh-fruit market; dried peaches are for the most part Muir and Lovell. In general, eastern-grown peaches do not make attractive dried products, but the freestone varieties can be successfully dehydrated.

Although mechanical dehydration is possible (table 28), nearly all of the commercial production of dried peaches is by sun-drying in California. In normal times a substantial portion is exported. Preparation for drying is similar to that for apricots. Trays are loaded with a layer of halves, with cup sides up.

PEARS

Pears are a minor fruit, in terms of tonnage. California, Washington, and Oregon produce almost three-fourths of the national crop. The Bartlett is the leading variety and is the only one that is extensively dried. Few pears are dried commercially outside California and most of the production there is by sun-drying. Although the Bartlett pear is the only variety dried commercially, other varieties can be dehydrated artificially. The Kieffer, which is grown in eastern States, can also be dehydrated but has two objectionable features: difficulty of ripening and a gritty texture. Pears are first washed to remove spray residue. After ripening, they are prepared by cutting in half and removing the calyx. The halves are spread on trays, sulfured 24 to 48 hours, and then exposed to the sun for 2 to 3 days; drying is completed in the shade in tray stacks. If pears are to be dehydrated, it is advisable to steam blanch for 20 to 30 minutes prior to sulfuring.

PRUNES AND PLUMS

Prunes are important among dried fruits, most of the crop being dried. Sun drying is feasible and about half of the California crop is processed by that method. In States north of California the climate does not permit sun drying, and dehydration is the only method used. In normal times dried prunes are exported in substantial quantities.

The French prune is most commonly dried in California; in Oregon and Washington the Italian is the leading variety, and others are dried to a lesser extent. Plums other than prunes can be dried only with difficulty, but could be dried if the need arose. Prunes have the special advantage of drying well with the stone intact and without fermentation. The preparation treatment consists of dipping in a hot lye or sodium carbonate solution in order to check the skins. This procedure is always used with prunes to be dried in the sun but is not essential when dehydration is used. In fact, when the latter method is used a cold-water wash is more satisfactory. Prune powder is made by a process similar to that used to make apricot powder. The dried prunes are first pitted; then they are ground, and dried to a low moisture content in vacuum.

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