tables by means of heated air. The air supplies the heat required to evaporate the water, and carries the water vapor away from the fruit or vegetable.

The drying process may be divided into two periods, based on the rate at which water is released from the solid material. During the *constant-rate* period, the amount of water evaporated per unit area per unit of time is constant. During the *falling-rate* period, the amount of water evaporated per unit area per unit of time decreases steadily. The constant-rate period is observed with materials of fairly high moisture content, and reflects conditions where evaporating surfaces are readily supplied with moisture from the interior of the fruit or vegetable piece. The evaporation rate during the constant-rate period is not limited significantly by the rate of transfer of moisture from the interior of the piece to its surface. The temperature, humidity and velocity of the air are the principal rate-determining factors. These external factors determine how rapidly heat can be supplied to the material from the air stream and how rapidly the water vapor can be transferred from the evaporating surface to the air stream. The falling-rate period begins when water cannot be supplied to the evaporating surface from the interior of the piece as fast as water vapor can be removed from the surface.

For most commodities that lend themselves well to dehydrofreezing, drying to approximately 50 percent of fresh weight involves only the constant-rate period, and the dryer operates exclusively under conditions where the demand for heat is high. Under these conditions, drying rate and the capacity of the dryer depend primarily on the velocity, temperature and humidity of the air if the exposure of evaporating surfaces to the air stream is adequate.

Control of air humidity in the drying step of the dehydrofreezing process is important only as a way to control product temperature. Product temperature influences the rate of darkening (both enzymatic and non-enzymatic), migration of sulfur dioxide in apple tissue and other events which may require control. For example, apple slices may be dehydrated at a low piece temperature so that enzymatic browning does not proceed rapidly enough to affect product quality. Apple slices may also be treated with sulfur dioxide to control enzymatic browning during drying at higher piece temperatures. In this case, control of piece temperature is important to insure proper penetration and migration of the sulfur dioxide within the apple slices.

As long as drying is in the constant-rate period, freely evaporating surfaces are usually near the wet-bulb temperature. Many measurements of the temperature of vegetable pieces during drying show that the product remains within a few degrees of the wet-bulb temperature well past the point of 50 percent weight reduction. In dehydration of vegetables for dehydrofreezing, product temperature is controlled primarily by controlling the wet-bulb temperature or the humidity of air entering the dryer.

Product temperature during drying of fruits is less easily specified and controlled. Fruit pieces remain near the wet-bulb temperature if the humidity of the air is high enough so that the surfaces of the fruit remain moist. However, if the humidity is too low and the fruit surfaces are dried out with the formation of a *skin*, piece temperature will rise well above wet-bulb temperature.

Freezing and Packaging

All dehydrofrozen fruits and vegetables to date have been packed for institutional use or remanufacture in 5 or 30 lb containers. No particular problems have been encountered in the packaging or freezing of these products. In the case of vegetables, the temperature of the partially dried material is usually close to the wet-bulb temperature of the drying air, regardless of its dry-bulb temperature, since dehydration is terminated before an appreciable reduction in the drying rate occurs. In most drying operations, the wet-bulb temperature will not rise much above 110–120 F unless considerable recirculation of air is employed or special techniques are used to increase the humidity of the air. In normal handling, the temperature of the partially dried material has cooled sufficiently for packaging without resort to special methods for cooling.

Apples and pimientos have been frozen in tunnels or sharp freezing rooms in 5 and 30 lb containers while peas have been frozen on trays prior to packaging. The latter method makes it somewhat more difficult to control precisely the solids content or the amount of dehydration, since additional and variable amounts of water are lost during freezing.

DRYING PROCEDURES AND EQUIPMENT

Static Bed Drying

The quality of a dehydrofrozen product depends a great deal upon the drying operation since overdrying prevents the pieces from rehydrating properly. Uniformity of drying within a piece as well as for different pieces is essential for a dehydrofrozen product of consistently high quality. A mixture of pieces dried to 30 percent weight reduction and pieces dried to 60 percent weight reduction will not, for example, make an acceptable product because the overdried pieces will not rehydrate properly. Furthermore, the lack of uniformity of drying results in unequal amounts of product in packages of the same size. Existing commercial static bed dryers of conventional design do not produce partially dried material of satisfactorily uniform moisture level. This is particularly true of dehydrators in which the material remains as a stationary bed of substantial thickness on belts or trays. In truck-and-tray tunnel dehydrators the product on top and along the leading edge of the trays will over-dry as compared with the material in the center of the tray bed. Drying is more uniform when the trays or belts are very lightly loaded, but the resulting loss of dryer capacity would be objectionable. Uniform drying without loss of dryer capacity is possible if the product is continuously mixed while drying, and this is done in the case of peas, apple slices and diced material such as carrot and potato cubes.

Certain soft fruits such as apricots cannot withstand even gentle mixing while drying and hence are tray dried, with the cut portion facing up to minimize leakage of juice. The halves are carefully placed on the trays in a single layer and special precautions are taken to insure uniform exposure of the pieces to the air stream. The drying method is an expensive one because of the large amount of labor involved in the traying and de-traying operations. Contamination of the product with wood splinters is also a serious problem where the drying trays are of wood. Despite these and other shortcomings, static bed tray drying is used because it is the only presently available method for soft fruits.

Belt-Trough Dryer

The need for a dryer capable of partially drying fruit and vegetable pieces to a uniform moisture level led to the development of a new type of dehydrator, known as a belt-trough dryer. The dryer (Fig. 4) consists essentially of an endless wire-mesh conveyor belt supported and transported by roller chain sprockets mounted on three drive shafts. All three shafts rotate in the same direction and at the same speed. The conveyor belt between the shafts thus forms a trough, with the bottom resting on an inclined, flat-surfaced air grate.

Fresh material is fed into the dryer at one end of the trough and is tumbled and conveyed by the belt, which moves in a direction at right angles to movement of the product. The partially dried material is discharged over an adjustable weir located at the opposite end of the dryer.

The drying air is heated by direct combustion of gas at the intake of an elbow-type axiflow fan and is delivered by the fan, via ductwork, up through the air grate, the conveyor belt and the bed of product. Air discharged from the dryer is collected and brought to the outside by a powered roof ventilator.

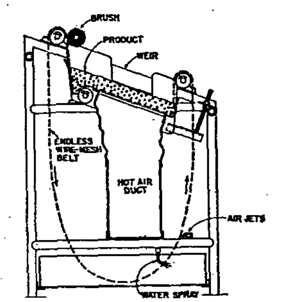

Fig. 4 .... Construction of a Belt-Trough Dryer

The belt is continuously cleaned by a rotary brush and hot-water sprays immediately upon leaving and before reentering the product bed. The dryer trough is inclined both laterally and longitudinally. The amount of tilt is adjustable in both directions to produce a product bed of substantially uniform depth.

The drying air moving up through the bed causes some fluidization of the material, and at higher velocities causes some of the smaller pieces to become airborne and be carried out of the dryer. The size, shape and density of the pieces limit the maximum bed depth, because these three characteristics determine the velocity at which the material will become airborne. The maximum effective bed depth for most vegetables diced 1/4 or 3/8 in. cube is approximately 3–5 in. Actual bed depth can, of course, be less than the maximum and is controlled by adjusting the height of the discharge weir.

Unusually high drying temperatures are possible in a belt-trough dryer because of the continuous mixing action that prevents the pieces from staying in a high temperature zone long enough to be damaged. Carrots, celery and pimientos diced 3/8 in. cube have been dried to 65 percent weight reduction with an air inlet temperature of 275 F without detectable heat damage. These higher drying temperatures cannot be used, of course, once the material is beyond the constant-rate phase of drying.

One commercial installation of belt-trough dryers used 5 machines, each of which had a capacity of approximately 1300 lb of fresh material per hr when drying down to 50 percent reduction with an air inlet temperature of 275 F. This corresponds to an evaporative capacity of 650 lb of water per hr.

Economic Advantages of Dehydrofreezing

The economic advantage of dehydrofreezing arises, in the main, from the savings in the weight and volume of the packed product. These savings come from two main factors (1) dehydration of the product to about 50 percent weight reduction, with the accompanying volume reduction; and (2) elimination of sugar, sirup, brine or water that may be packed with the frozen or canned products. Other savings may arise from the use of lighter weight and less costly containers.

The reduced weight and volume of dehydrofrozen products can result in important savings in the costs of packaging materials, storage and transporation. In addition to these savings are those more difficult to assess without engineering analysis. These other savings result mainly from the lesser weight to be packaged and handled in both the production plant and in the kitchen or factory of the user.

Estimated comparative costs of packaging, storage, and transporting several dehydrofrozen, frozen, and canned products are summarized in Table 1. The cost advantages shown are apparent and easily calculated. Still other cost advantages are less easily estimated. There are additional savings in handling costs at every stage of the marketing chain. Perhaps most important of all is the savings to the user who can store twice the equivalent quantity of dehydrofrozen foods and has less weight to handle in his kitchen.

The most obvious additional cost of dehydrofreezing over freezing is the added step of dehydrating. The amount that this step adds to processing costs depends largely on the availability of drying systems that will partially dry the material satisfactorily and uniformly with a minimum of labor requirement. The related power and fuel costs are minor considerations. More important are the cost of the dehydrator and the effects of changes that may occur in operating and maintenance procedures. Estimates made by prospective users of the dehydrofreezing process indicate that any changes in overall processing costs will be very small compared to the savings in packaging, storage and transportation costs.

An overall cost comparison of the three forms of products considered can be made only if all steps in the production, marketing, and distribution chain are evaluated. Final evalu-

Table 1 .... Approximate Costs of Containers, Storage[a] and Transportation[b] for Dehydrofrozen, Frozen and Canned Products from 100 Lb of Raw Material

	Dehydrofrozen				Frozen				Canned			
	Container	Storage	Transport	Total	Container	Storage	Transport	Total	Container	Storage	Transport	Total
Carrots	$0.55	$0.55	$0.85	$1.95	$1.15	$1.10	$1.70	$3.95	$2.10	$0.50	$2.10	$4.70
Peas	0.65	0.65	1.05	2.35	1.35	1.30	2.05	4.70	2.45	0.60	2.55	5.60
Pimientos	0.30	0.30	0.45	1.05	0.85	0.85	1.25	2.95	1.20	0.30	1.10	2.60
Apples	0.50	0.50	0.75	1.75	1.10	1.05	1.65	3.80	1.20	0.30	1.25	2.75
Apricots	0.55	0.70	0.95	2.20	1.25	1.35	2.30	4.90	1.65	0.40	1.65	3.70

[a] Six months' storage.
[b] Shipping from West Coast to Chicago area.