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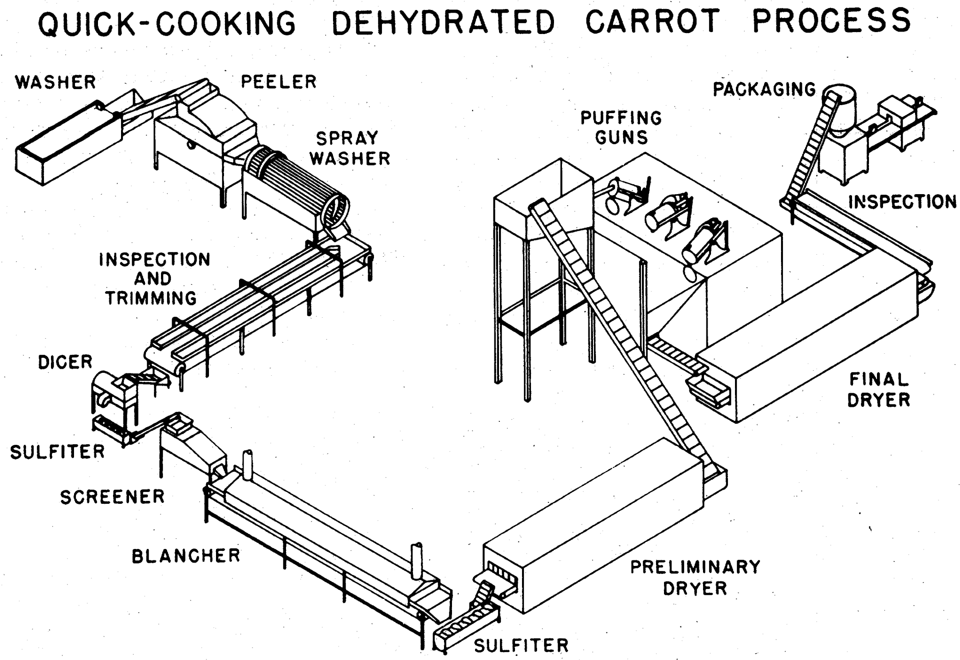

FIG. 1—Flow sheet shows essential steps in carrot process as it may be done commercially. Note puffing guns from left to right are in loading, operating, and firing positions respectively.

Explosive puffing process produces . . .

Quick-Cooking Dehydrated Vegetables

Puffing gun is used for diced carrots and beets that reconstitute rapidly. Process is commercially feasible

CURRENT INTEREST in convenience foods has stimulated research on various dehydration methods. Freeze-drying techniques especially have advanced in the last decade. And costs have been reduced through improved equipment and integration of operations. But freeze-drying is still expensive. It is generally limited to products which cannot be dehydrated successfully by cheaper methods.

Moreover, some products, celery and onions for example, lose much of their flavor when subjected to the low pressures employed in freeze-drying. They can be inferior to the products dried in hot air at atmospheric pressure.

The continuous drying of foamed concentrates and slurries at low pressures is expanding commercially. Recently, foams have been dried by spraying (Ref. 1, 2, 3) and as a mat (4, 5, 6, 7). These procedures however are workable only with liquids and not with food pieces such as dice and slices.

The well-known methods of drying diced or sliced fruits and vegetables in hot air are limited by: (1) the size of piece that can be dried in a reasonable time, and (2) the long times required to reconstitute the products. Products in the form of dice (3/8-in. cubes) are about as large as can be dried feasibly by conventional hot air dehydration methods. They require about 20 to 25 min. boiling to reconstitute in the case of potatoes, 35 to 45 min. for carrots, and 45 to 55 min. for beets.

There has long been a need for a dehydration process: (1) operable at moderate cost, (2) applicable to relatively large pieces of fruits and vegetables, and (3) yielding products capable of rapid reconstitution. To that end research has been in progress for several years in the Engineering and Development Laboratory of the Eastern Utilization Research and Development Division.

A pilot plant process is now under development (8, 9), which has

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been successfully applied thus far to potatoes, carrots, beets, apples, blueberries and cranberries. In this process, the vegetable or fruit piece is partially dehydrated. Then its structure is made porous by explosion-puffing and the porous piece is dried to low moisture content.

Process for Carrots

A flow sheet of the process for carrots as it might be carried out commercially is shown in Fig. 1. The operations of lye-peeling, trimming and dicing can be done by conventional methods. In the pilot plant work reported in this paper, washed and topped carrots were used, mainly of the Red Core Chantenay variety. A few tests on Imperator variety have been made. Both varieties have given an excellent quality dried product.

The carrots were peeled by immersion for 1½ min. in 20% by weight solution of NaOH at 160F. The lye-softened skins were then removed by high-pressure water sprays. The peeled carrots were dipped in a solution of 0.5% by weight $NaHSO_3$ and 0.5% by weight citric acid. This dip was considered necessary in pilot plant batch operations where considerable delay was occasionally entailed in trimming. It is not shown in Fig. 1 since we believe there would be little holdup on a commercial "merry-go-round" trim table.

Little trimming was required. The green caps were removed from the stem end and thin roots from the bottom ends. Trimmed carrots were cut to nominal ⅜-in. cubes in an Urschel Model B dicer. The whole output from the dicer was immediately dipped for ½ min. in the $NaHSO_3$-citric acid solution previously mentioned.

Size distribution of the cut pieces varied somewhat with the size of the carrots, sharpness of the dicer knives, rate of feed to the cutter, etc. A Day-Roball screener fitted with stainless steel wire-slotted screens was used to determine size distribution. This is shown along with peeling and trimming losses in Table 1. As indicated in the table, about 9% (6.2% of the raw carrots) of the cut pieces pass through a screen with slots ⅛ x 2 inches.

Although the entire output of the dicer has been successfully processed without separation in the pilot plant, recommendation is that it be separated in a commercial line (Fig. 1). The fraction passing the ⅛-in. screen, by reason of its smaller size would otherwise be dried to a lower moisture content than the larger pieces in the initial drying step and might scorch (Fig. 4, scorch area) in the guns.

TABLE 1. Processing Losses In Pre-Drying Operations

(Pilot plant tests on nominal ⅜-in. carrot dice)

Basis: 100 lb. raw carrots

Operation	Pounds Recovered	Loss, % of Raw Carrots
Raw carrots	100	—
After peeling	76	24
After trimming	72	4
After dicing	68.2	3.8
Screening:		
Over ⅛-in.	61	1
Through ⅛-in.	6.2	1
After blanching	54	7*

*Based on blanching the "over ⅛-in." fraction only (61 lb.)

The separated pieces are small enough to be dried completely without puffing and will rehydrate quickly.

The diced, dipped pieces passing over the ⅛-in. slotted screen are blanched for 4 min. in steam at atmospheric pressure. Tests for peroxidase enzyme indicate 85% inactivation at this point. For protection during dehydration, and to ensure an SO_2 content of between 500 and 100 ppm in the finished product, the blanched pieces are immersed for 30 sec. in a bath containing ¼% sodium bisulfite and ¼% citric acid.

(A) First-Stage Drying

To prepare pieces for the explosive-puffing step which imparts the quick-cooking properties, it is necessary to remove a large part of the water. Otherwise the pieces will disintegrate on explosion. For each fruit and vegetable there is a range of moisture content optimum for puffing. This range may vary slightly depending on piece size and weight of charge with respect to gun volume. For nominal ⅜-in. carrot dice (with which most pilot plant work has been done) the moisture content entering the puffing step should be in the range of about 30-42%.

Initial drying may be done in a continuous belt-type hot air drier under conditions commercially feasible. Pilot plant drying was done on a tray drier (National Drying Machinery Co. Cabinet Type) under conditions simulating commercial practice. Dice passed over ⅛-in. screen were loaded to a depth of 3 in. on a 28 x 28-in. square perforated bottom tray.

Air was passed upward through the bed at 200F. dry-bulb temperature and about 200-ft./min. velocity for approximately the first half of

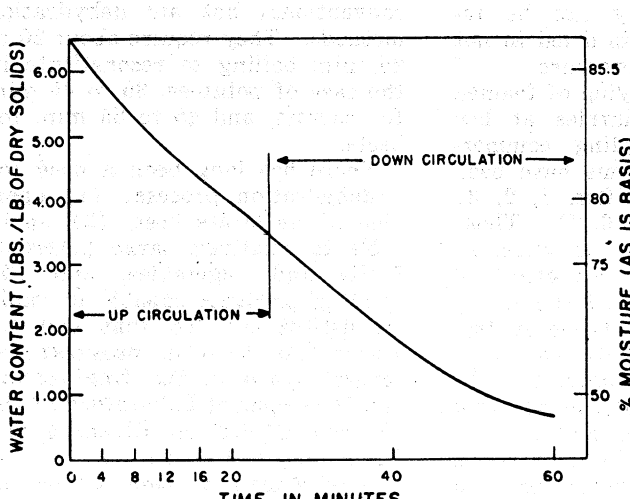

FIG. 2—Air passed upward through bed at 200F. and 200-ft./min. velocity, and downward for remainder of 1-hr. cycle in initial drying.

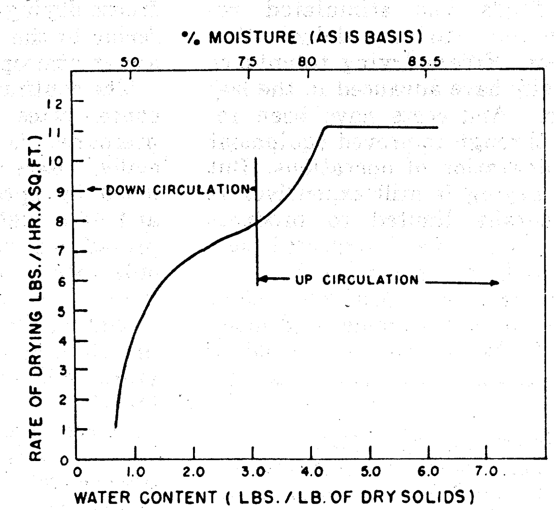

FIG. 3—Drying rate was steady and high from moisture content of 86% down to 81%. Then rate fell to about 1 lb./hr./sq. ft. drying surface at 40%.

the drying cycle, and downward through the bed for the remainder of the 1-hr. cycle (Fig. 2).

As shown in Fig. 3, the rate of drying was constant and highest (11 lb./hr./sq. ft. of drying surface) from the initial moisture content of about 86% (6.1 lb. water/lb. solids) down to about 81% (4.25 lb. water/lb. solids).

During the falling rate period, the rate declined rapidly to about 1 lb./hr./sq. ft. of drying surface at a moisture content of about 40% (about 0.65 lb. water/lb. solids).

In the pilot plant drying tests, the product was not stirred on the tray. Change of air flow direction at the half-way point was relied upon instead. This yielded the uniformity of moisture content required for adequate puffing of all pieces. During drying the bed-depth decreased to 3/4 in. through shrinking of the pieces.

(B) Explosion-Puffing

In explosion-puffing, the partially dried pieces from first-stage drying are heated in a closed, rotating chamber or "gun" until a predetermined pressure is developed by vaporizing a very small amount of water from them. A suitable pilot plant or small factory unit has been described (9).

When the gun is discharged to the atmosphere a small percentage of the water still contained within the pieces is instantly vaporized, having been superheated above its atmospheric boiling point. During explosion, the formation and escape of a small amount of water vapor from the pieces creates pores and cavities within them which communicate with the outer surface. This porosity makes possible rapid final dehydration and rapid rehydration of the finally dried pieces. In the case of carrots, the pieces are dried to a moisture content of 4% (determined by Karl Fischer method).

In order to ensure uniform rehydration properties, the moisture content-pressure relationship must be carefully controlled. As shown in Fig. 4, exploding at too high a pressure causes scorching at low moisture content or disintegration at high moisture content. Too low a pressure fails to puff the pieces.

As far as puffing is concerned, all conditions enclosed within the line of Fig. 4 are satisfactory. Moisture contents to the right of the vertical dotted line are too high, however, for other reasons that will be discussed later under "Final Drying." Moisture contents within the solid line and to the left of the dotted line are satisfactory in all respects.

For 3/8-in. carrot dice, exploding at 35% moisture content and 35 psig pressure is optimum and leaves considerable room for inadvertent pressure or moisture-content variations. Tests for perioxidase on the dice as discharged from the gun indicate complete inactivation.

(C) Final Drying

Carrot pieces entering the explosion-puffing step at about 35% moisture content enter the final drying step at about 30%. The 5% drop was accomplished by the flashing of vapor during exploding. When explosion puffing has been done under the proper conditions, the product can be dried rapidly to a moisture content of 4% in a single-stage, continuous-belt, hot-air drier.

Experiments on the second-stage drying were done using a pilot plant tray drier in the same manner as described for the initial drying tests. Commercial practice was simulated. Trays were loaded to a depth of 4 in. with the explosion-puffed dice. They were dried with an air velocity of over 200 cfm and an air temperature of 150F. dry bulb. On the basis of the pilot plant test, commercial bin drying should not be required.

Fig. 5 is a series of three final drying curves for carrot dice exploded at the same pressure (35 psig) but at different moisture content, and one drying curve for dice dried without puffing. A comparison of these curves shows the more rapid drying of the exploded dice at all moisture contents compared to the dice dried without exploding.

From the three curves for the dice exploded at different moisture contents it is evident that exploding at lower moisture produces a faster drying product. This apparently is due to the pieces exploded at higher moisture contents partially collapsing after explosion or during drying.

The product exploded at 37.8% moisture content apparently remained rigid in structure, without collapse. It reached a moisture content of 4% ("as is" basis) after a drying time of 110-120 min. None of the other products reached 4% moisture content even after 180 min. drying, although the product exploded at 41.4% moisture content approached it.

The effect is perhaps more easily seen in Fig. 6 where drying rate is plotted against water content of

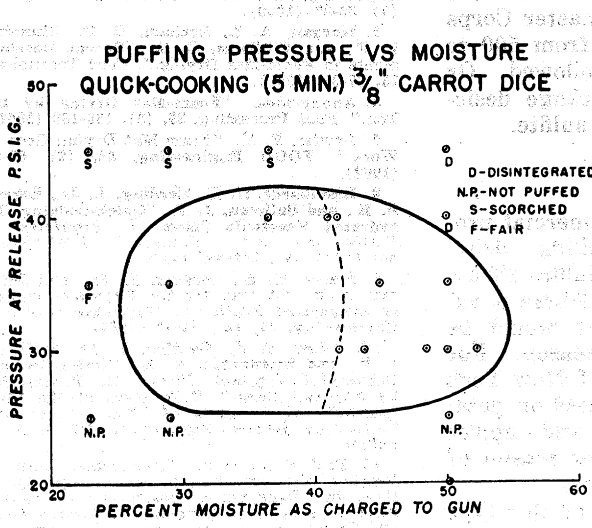

FIG. 4—Conditions within the line are satisfactory for puffing. Too high pressure causes scorching or disintegration, too low fails to puff the pieces.

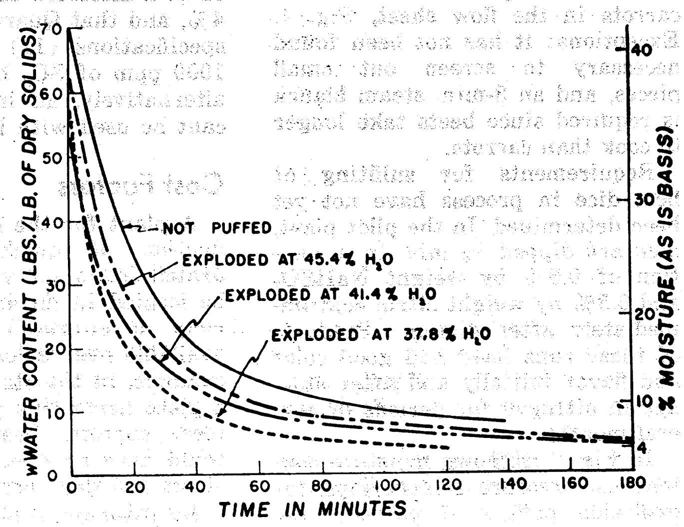

FIG. 5—Three final drying curves for carrot dice exploded at same pressure (35 psig) but at varying moisture content, and one curve without puffing.

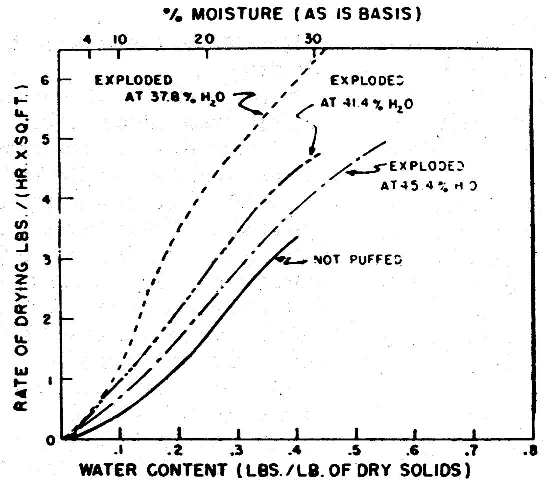

FIG. 6—Product exploded at lowest moisture content (37.8% top curve) had a drying rate of 6 lb./hr./sq. ft. drying surface. Others were at 4.5, 3.8 and 3.4 lb./hr./sq. ft. respectively.

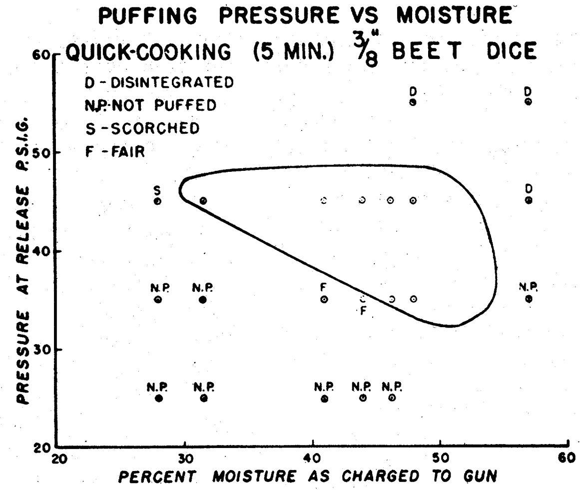

FIG. 7—Pressure-moisture relationships show optimum conditions for beet dice to be about 45 psig pressure and 45% moisture where widest latitude for variation exists.

the drying pieces. The product exploded at the lowest moisture content (37.8%, top curve) had a drying rate (at a water content of 0.4 lb./lb. solids) of about 6 lb. water/sq. ft. of drying area per hour. The others were 4.5, 3.8, and 3.4 lb./hr./sq. ft., respectively.

The drying rate curve for the preferred product (top curve) changes direction at a moisture level of about 0.12 lb./lb. of dry solids (10.7% moisture on the "as is" basis). It appears that near this moisture level removing water from the tissue becomes more controlling than removing it through the pores. Hence, porosity has less effect on drying rate as moisture content approaches the minimum.

Process for Beets

Beet dice (3/8-in. cubes) have been prepared successfully by basically the same process as shown for carrots in the flow sheet, Fig. 1. Exceptions: it has not been found necessary to screen out small pieces, and an 8-min. steam blanch is required since beets take longer to cook than carrots.

Requirements for sulfiting of beet dice in process have not yet been determined. In the pilot plant, dice are dipped ½ min. in a solution of 0.5% by weight $NaHSO_3$ and 0.5% by weight citric acid immediately after dicing. Products of these runs have had good color and flavor initially and after storage in nitrogen for periods of several months.

In Fig. 7 is shown moisture content vs. pressure relationships for explosion puffing of partially dehydrated beet dice. From this it appears that the operation can best be accomplished at about 45% moisture and 45 psig pressure. At these conditions, widest latitude for variations of pressure and moisture exists.

Storage Properties

Storage tests have not yet been made on quick-cooking dehydrated carrots or beets. Observation shows that the color and flavor of the carrots are generally superior to the freeze-dried product. But it is not known whether this superiority endures throughout storage. Reports (11) indicate that best flavor and carotene retention in conventionally hot-air dried carrots is achieved by nitrogen packing and using an in-package desiccant to reduce moisture below 2%.

Without specific data on the explosion-puffed product, recommendation is: that it be nitrogen packed at a moisture content not above 4%, and that Quartermaster Corps specifications (12) of from 500 to 1000 ppm of SO_2 be followed. Or alternatively, an in-package desiccant be used with less sulfite.

Cost Factors

A plant for the commercial production of quick-cooking dehydrated fruits and vegetables should be located in an area where a variety of commodities would be available over a long season. For example, in the state of New York a plant using this process on potatoes, carrots, beets, and apples could have an operating season of about 300 days per year.

By estimate, a plant of this type operating from Sept. 16 to Dec. 10, at a capacity of 62.4 tons of carrots per day (11,520 lb. of product) could produce quick-cooking 3/8-in. carrot dice at a cost of only about 12% above that for conventionally hot-air dried carrot pieces of the same size. The extra cost derives mostly from the labor involved in puffing. The additional cost of the guns is largely offset by the greatly reduced drying facilities required. (End)

NOTE: Reference to certain products or companies does not imply an endorsement by the Department over others not mentioned.

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