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Dehydrated Explosion-Puffed Apples

ABSTRACT

A new method for preparing dehydrated, explosion-puffed apple pieces is described. The shortened cycle, made possible by direct injection of superheated steam into the puffing gun, has significantly improved product quality and increased throughput rates. Processing details, product preparation and evaluation, and storage results are given.

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DEHYDRATED EXPLOSION-PUFFED APPLES

N. H. Eisenhardt, J. Cording, Jr.,

R. K. Eskew,* and W. K. Heiland

INTRODUCTION

Explosion-puffed, dehydrated fruit and vegetable pieces possess a highly porous structure. This attribute gives the puffed material quick-cooking properties in contrast to the slow rehydration of conventional, air-dried pieces of equal size. Another advantage is a crisp texture, which in apple lends itself readily for use as a snack item.

The explosive-puffing process for fruits and vegetables was developed at the Eastern Utilization Research and Development Division (1).† The process has been successfully applied to many commodities, including white potatoes (3, 4, 16), carrots (2, 4, 12, 15), beets (2), sweet potatoes (13), blueberries (5, 6), and apples (5).

Major changes in puffing equipment and processing techniques have greatly improved both product quality and output rate to the point of commercial feasibility. The key to the present short cycle is the use of superheated steam under pressure as the primary means to obtain quickly the superheat required for puffing. This, coupled with external heating to minimize heat loss, has sharply reduced heat exposure time and resulted in corresponding product quality improvement. Publications on the modified puffing gun and process applications are cited (6, 7, 14, 15, 16).

These changes have made some of the earlier publications obsolete. The purpose of this report is to present current findings on apple, superseding those in the previous publication (5).

PROCESS DESCRIPTION

The procedures used in preparing dehydrated, explosion-puffed commodities usually include the following: (1) raw material preparation, (2) partial drying to a moisture content suitable for puffing, (3) equilibration, (4) explosive-puffing, and (5) final drying to a low moisture content. Separation, sorting, inspection, and packaging are common to all, but vary in degree or kind, or both, depending on the commodity and specific product.

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*Present Address: Box 205, Spring House, Pa. 19477.

†Underscored numbers in parentheses refer to literature cited at the end of this report.

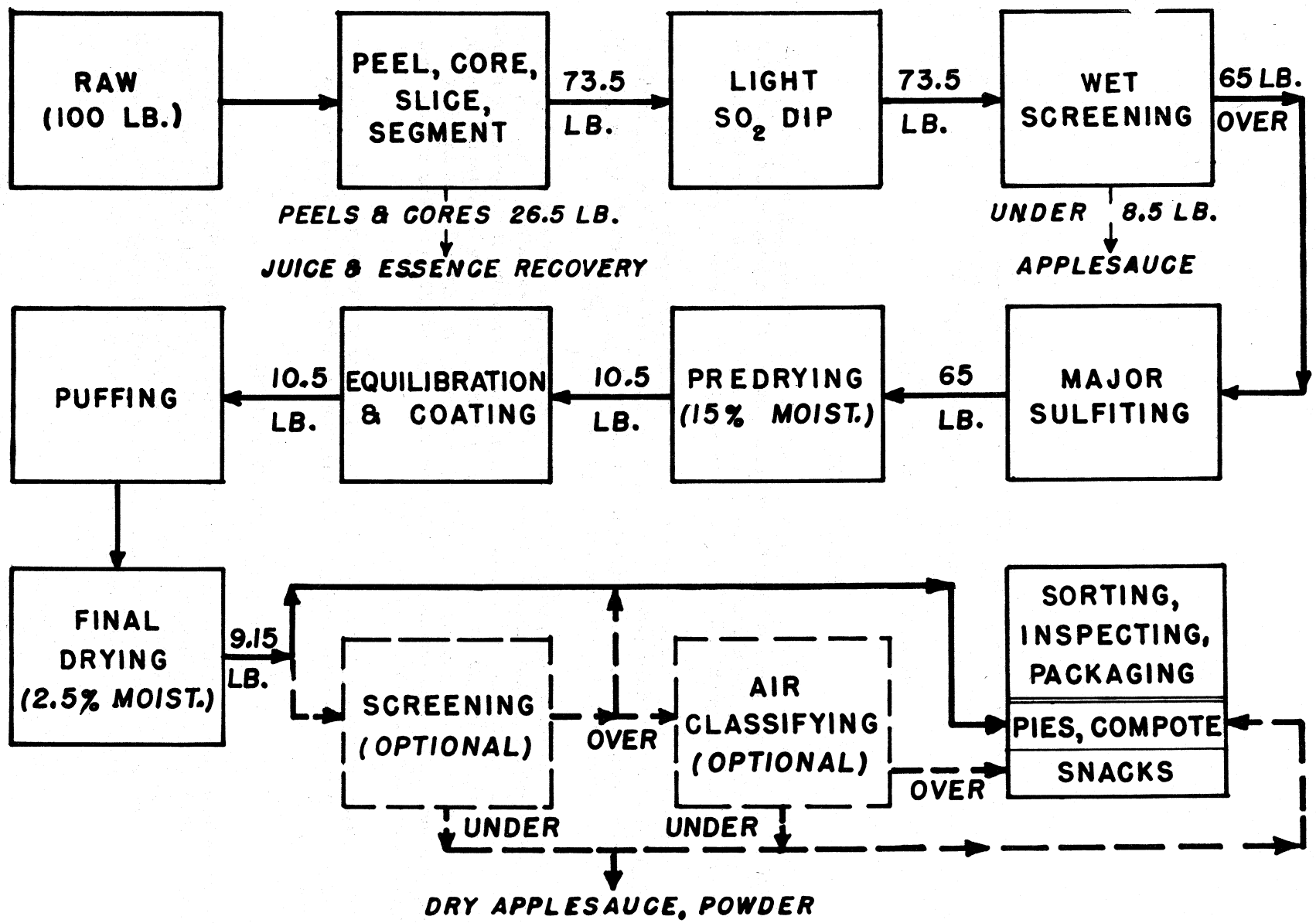

Figure 1. Processing flowsheet for dehydrated explosion-puffed apples.

Figure 1 shows the processing steps used in pilot plant studies to prepare explosion-puffed, dehydrated apples. The flowsheet is for half-segments, i.e., 16 longitudinal slices cut in half (32's). This piece configuration is a reasonable compromise between whole segments and dice, and can be incorporated in pies, compotes, or eaten "as is" for snacks. Material not suitable for use as above can readily be ground for use in applesauce or bakery mixes. Most data were obtained on the York Imperial variety, a typical, hard, processing apple, and the following presentation pertains primarily to this variety.

RAW MATERIAL PREPARATION

Mature, sound apples, 2-1/2 to 3 inches in diameter, were mechanically peeled, cored, sliced, and segmented.* The peels and cores could be used to make concentrate and essence in a commercial operation (10, 11).

A one-minute static dip in a 1/2-percent aqueous solution of sodium bisulfite was used to preserve color during screening. Removal of undesirable fines, residual carpel tissue, and seeds was found necessary to reduce non-uniformity of product. The half-segments were passed over a vibrating screen equipped with slots 3 inches long and 5/16-inch wide. Feed rates up to 261 lb./hr. x square foot of screen were successfully used. Approximately 12 percent of the feed passed through the screen and had a residual SO_2 content of 3,500 p.p.m. on a moisture-free basis (MFB). This fraction after suitable cooking and finishing might be used for making dehydrated sauce by drum drying (8). The fraction passing over the screen was further sulfited by immersion for 5 minutes in a circulating solution of 2 percent sodium bisulfite (70° F.) to bring the residual SO_2 content to 11,000 p.p.m. (MFB). Apple maturity, variety, and length of storage affect the pick-up and retention of SO_2, hence the dip times and concentrations are presented only as guidelines. It is recommended that the level of SO_2 in the dried, explosion-puffed product be from 300 to 500 p.p.m.

PARTIAL DRYING

Partial dehydration is necessary to reduce the moisture content to a suitable level for puffing. For apples, the range is between 12 and 18 percent on a wet basis. Too high a moisture would result in a piece disintegration or in collapse of the porous structure formed.

Commercially, initial drying would probably be done in a through-circulation continuous belt dryer or in a belt trough dryer (9). Drying studies in the pilot plant were done in a cabinet-tray dryer† under conditions applicable to commercial practice. Perforated stainless steel trays were coated with a food grade silicone parting agent, such as used in bakeries, to prevent sticking of the pieces. Trays were individually loaded to bed depths of 2, 4, and 6 inches, corresponding to 6.6, 12.1, and 17.7 lb. per sq. ft., and dried with throughflow hot air at 180° F. dry bulb and 100°-110° F. wet bulb, initially either in a downflow or upflow direction, at about 250 f.p.m. velocity. In all experiments, air direction was reversed halfway through the drying cycle, the beds were either allowed to remain static or were mixed, and drying was continued until the desired end-

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*Equipment manufactured by F. B. Pease Co., Rochester, N. Y.

†National Drying Machine Co., Philadelphia, Pa.

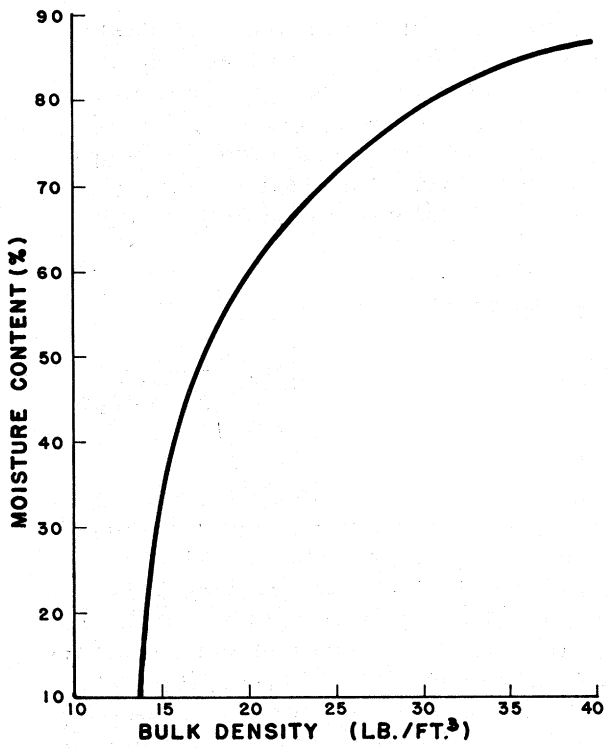

Figure 2. Bulk densities of apple pieces during drying.

moisture of 15 percent was reached. Final bed depths were 0.70, 1.4, and 2.1 inches, tray loadings were 0.82, 1.63, and 2.45 lb. per sq. ft., and drying times were 2.0, 2.25, and 2.38 hours, respectively. Drying times at any given bed depth were about the same whether beds were static or mixed, or whether initial airflow was up or down. At bed depths greater than 4 inches, however, the pressure drop across the tray increased to a degree that power requirements might be a limiting factor on a commercial basis. Bulk densities at moisture contents encountered in preliminary drying are shown in Figure 2.

The plant operating season can be extended or scheduled for other fruit or vegetable processing, since the partially dried apple pieces can be bulk stored, for extended periods, as now practiced commercially. This is a distinct advantage in reducing equipment required to completely process the raw fruit at the height of the harvesting season and allowing slack periods to be profitably utilized by explosion-puffing and final drying.

EQUILIBRATING

The moisture distribution in and among the apple pieces is not uniform at the end of preliminary drying. If the material were immediately puffed, a non-uniform product would result, therefore a conditioning, or equilibration, period is recommended. Holding the pieces in a closed container for 16 hours at room temperature (c. 73° F.) is sufficient. Because of the high sugar content of the pieces, clumping may occur because of heating and partial steam condensation when puffing. Coating the half-segments with an anti-caking agent, such as ultra-finely divided, hydrated sodium silico aluminate, effectively prevents clumping and sticking. Zeolex 7,* equivalent to 1.5 percent by weight of apple solids present, was intimately mixed with the equilibrated pieces by tumbling for about 15 minutes. After puffing and final drying, the residual powder remaining was about 1 percent of the apple solids.

Zeolex (Sodium Silico Aluminate) is sanctioned by the United States Food and Drug Administration as an anti-caking and conditioning agent in foods up to 2 percent and by the Meat Inspection Division of the U.S.D.A. up to 2 percent in dry seasoning and curing mixtures used in meat or meat products. Zeolex is limited to 2 percent in the final food product because it has no nutritional value. Zeolex is exempt from the 1958 Amendment to the Food and Drug Laws and has GRAS (Generally Recognized As Safe) status. The generic name, Sodium Silico Aluminate, is used for label identity.

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*J. M. Huber Corp., Menlo Park, N. J.

in the course of drying. The final bulk density of the material at 2-1/2 percent moisture was 11.4 lb. per cu. ft. A comparison made with unpuffed pieces, dried from the same initial moisture (19 percent) under the same conditions, showed that after 6 hours of elapsed time the moisture content had reached only 3 percent. To achieve lower moistures for unpuffed material, vacuum drying would probably be required.

SCREENING AND SEPARATION

A typical size distribution of puffed, dried half-segments, prepared in the foregoing manner, is shown in Figure 4 as a plot of cumulative screen analysis. Unless uniformity of size is desirable in the product, i.e., for pies or compote, separation should not be necessary. Screening can be employed to obtain a desired size range, and the screen unders, after grinding, can be incorporated in dehydrated applesauce. In the case of snacks, where only fully puffed pieces are acceptable, further separation may be necessary. Advantage can be taken of the density difference between puffed and partially puffed pieces by using pneumatic separation. Pilot plant runs, with well-puffed, dehydrated pieces, showed that screening over 0.371 inch square mesh followed by air classification,* yielded as much as 50 percent of the gun charge suitable for snacks.

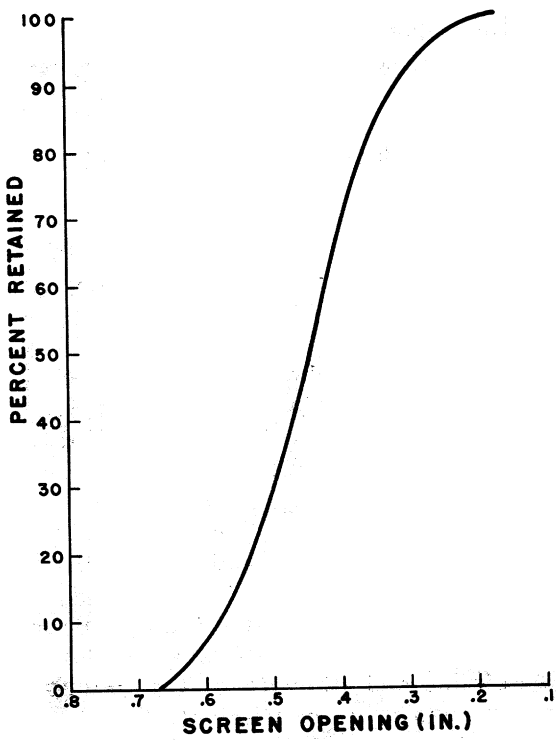

Figure 4. Cumulative screen analysis of dried, puffed half-segments.

APPLESAUCE PREPARATION

Explosion-puffed, dehydrated pieces not suitable for snacks or pies because of shape or size can be ground to a powder. Since the powder is hygroscopic, the grinding operation must be conducted at low relative humidity (20 percent maximum) usually in a room built especially for this purpose. The texture of the sauce can be controlled by the coarseness of the grind, usually not more than a U. S. Standard No. 12 sieve.

Experience at this Laboratory has shown that a desirable texture results if the pieces are ground so all pass a U. S. Standard No. 20 sieve. Adjustment of Brix-acid ratio is necessary to achieve a balance of sweetness and tartness. This requires addition of sugar and an acid, such as malic, to the powder. Addition of a food grade anti-caking agent, such as calcium stearate, to the dry ingredients prevents lumps from forming in the dry state. The ingredients must be intimately mixed at low humidity before packaging.

Seventy grams of applesauce powder, when reconstituted with 10 fluid ounces of hot or cold water, gives about 10.6 fluid ounces of sauce. We have found that applesauce with

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*Electric Sorting Machine Company (Houston, Tex.) Model 3000, Dry Products Separator.

7. Lower gun to firing position, stop rotation, release gun lid and shunt inlet steam to the bypass by closing valve (4).

8. Raise gun to loading position, introduce charge, close lid, lower to operating (horizontal) position, start rotation, relight gas burners, and introduce steam (4).

9. Maintain surface temperature at 330° F. Observe the temperature of superheated steam entering the gun as shown on recorder (7), and adjust thermostat (3) as necessary to achieve about 330° F. steam temperature (corresponding to about 65° F. superheat) entering the gun.

10. Steam pressure (6) will begin to rise as soon as valve (4) is opened. Adjustment of valve (2) may be needed to obtain desired pressure (6) at the completion of the steam cycle (about 1 minute).

11. At the end of the steaming cycle, repeat step 7. Product will be discharged and the cycle can be repeated starting at step 8.

Puffed apple pieces are discharged into a sloping tunnel designed to reduce the initial velocity at firing. The tunnel terminates in a tray from which the pieces would be conveyed to the final drying stage.

Puffed half-segments discharged from the gun are somewhat higher in moisture content than the original charge. The loss of water vapor occurring on puffing is exceeded by the amount of condensation resulting from superheated steam contacting the relatively cold charge; hence, a 15-percent moisture charge will usually be about 19 percent after puffing.

Loading, firing, and reloading should take about 1-1/2 - 2 minutes, and the heating cycle about 1 minute. It should be possible to process about 20 charges of 15 lb. each per hour, or the equivalent of 262 lb. per hour of puffed half-segments at a final product moisture content of 2.5 percent. The maturity of the apples, length of storage, variety, and piece size affect the bulk density of the pre-dried pieces and, therefore, the weight-volume capacity of the puffing gun. Overloading the gun results in insufficient steam distribution throughout the charge and inadequate tumbling of the pieces during the steaming cycle. The result is a non-uniformly puffed product, therefore it is recommended that the maximum charge size should not exceed 80 percent of the gun volume.

FINAL DRYING

The puffed material must be dried further to be stable, i.e., 2.5 percent moisture or lower. Commercially, drying would probably be done in a through-circulation belt dryer. Pilot plant studies were conducted using a cabinet-tray dryer with throughflow air at 150° F. dry bulb, 95°-100° F. wet bulb, at a velocity of about 250 f.p.m. Air direction was downflow throughout the drying cycle to prevent blowing the half-segments out of the trays. The bed depths were 2, 4, and 6 inches, corresponding to tray loadings of 1.9, 3.9, and 6.8 lb. per sq. ft. Approximately 2-1/2 hours were required to dry from 19 percent moisture to 2.5 percent. In 4 hours, moisture can be reduced to approximately 1.7 percent. Little difference existed in evaporative rates between 2-, 4-, or 6-inch beds, and no compression due to weight of puffed dice was detected at 6-inch depth. Six inches may not be the maximum depth that could be used. The material was not mixed

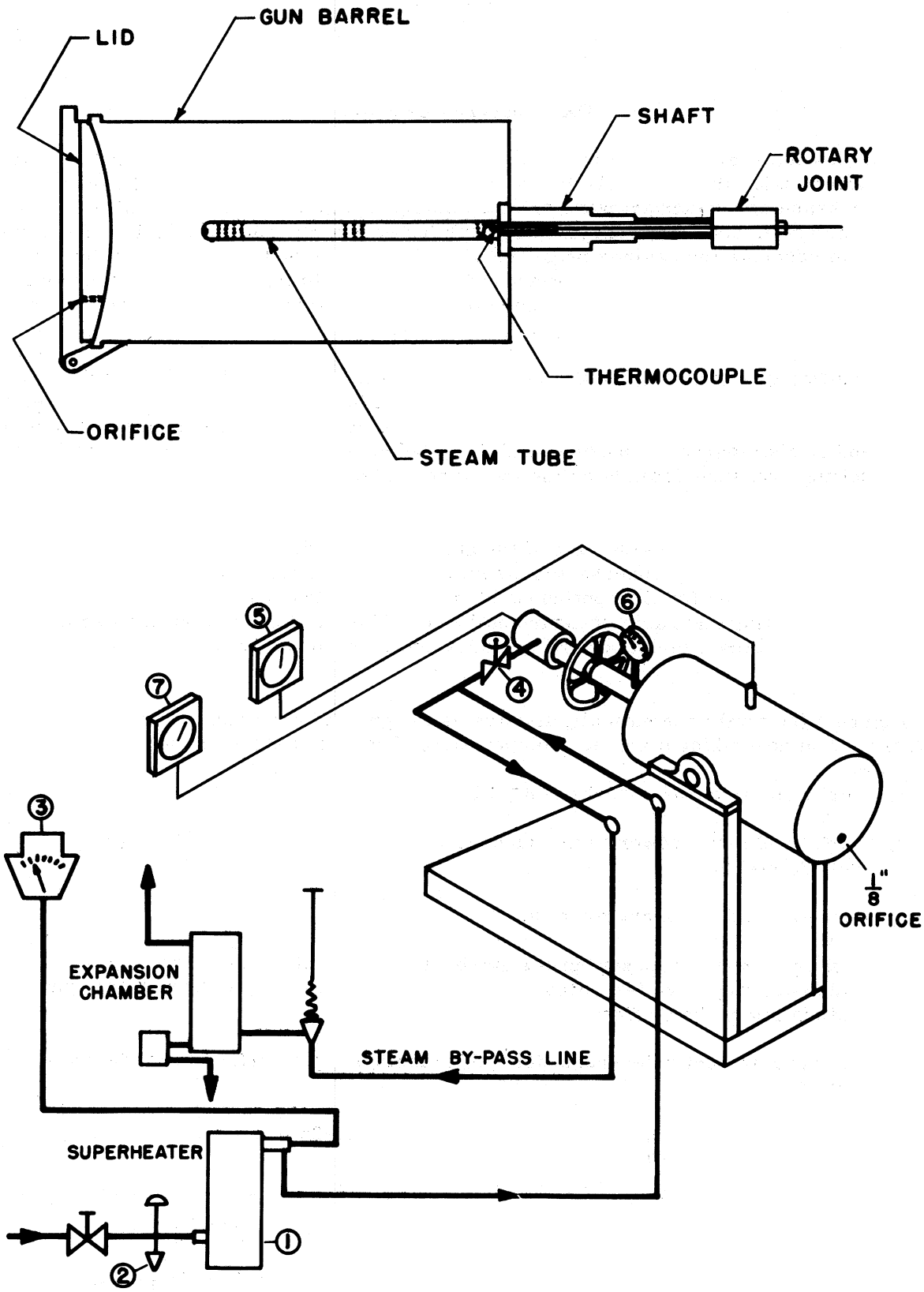

Figure 3. Details of puffing gun (top) and of controls for gun operation (bottom).

EXPLOSIVE-PUFFING

A porous internal structure is imparted to the half-segments when part of the superheated water inside the pieces flashes on discharge from the puffing gun. Formerly, steam pressure and superheat were obtained solely from the moisture contained in the charged material, and were generated by applying heat to the gun externally. The time required to generate the desired pressure often resulted in undesirable, heat-induced flavors in the product. Now the continuous injection and through-flow of superheated steam provides rapid superheat, pressure build-up, minimizes heat exposure, and results in a higher production rate.

The puffing gun used in pilot plant studies has sufficient capacity to be suitable for commercial use.* Charge sizes up to 15 lb. of apple half-segments have been successfully puffed in the range of 12 to 18 percent moisture content. Pieces above this moisture range tend to disintegrate on puffing, and those below tend to be hard and unpuffed. Optimum puffing pressure depends on the moisture content, i.e., higher pressure for lower moisture. Nominally, 25 p.s.i.g. would be used for 15 percent moisture pieces.

Figure 3 (top) is a cross-section of the gun and shows the perforated tube used for injection and distribution of superheated steam during operation. The orifice shown on the lid of the gun provides for the continuous steam through-flow that is necessary for uniform charge heating and rapid pressure build-up. The thermocouple at the steam inlet measures actual steam injection temperatures and is an important control means during gun operation.

Figure 3 (bottom) schematically illustrates the gun and operating controls and will be referred to in describing start-up and operation. Sequential steps are as follows:

1. Admit steam to the superheater (1) by opening valve (2).

2. Turn on electric power to the superheater and set thermostat (3) to give 475° F. steam.

3. Close gun lid and start rotation.

4. Light gas burners located under gun barrel and admit steam to gun through quick-opening valve (4). Steam is now flowing continuously through the gun and exiting at the orifice shown on the gun lid.

5. Set gas rate controller-recorder† (5) to maintain gun surface temperature at 330° F.

6. Adjust steam pressure with valve (2) to obtain 20-25 p.s.i. as indicated by gage (6) on gun shaft.

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*The gun is manufactured by Wilmot Fleming Engineering Co., Philadelphia, Pa.

†Gas control - skin temperature of the puffing chamber is measured by a sliding thermocouple in contact with the outer wall. To control this temperature automatically, an indicating, recording, and controlling instrument, connected to a gas regulating valve, controls the gas flow to the burners under the gun. An automatic ignition and shut-off system completes the gas control.

an apple solids to sugar ratio of 2.5 to 1, a Brix of 19.5°, and a Brix-acid ratio of 45 possesses pleasing flavor, texture, and consistency. Tests have shown that to retain initial quality at room temperature storage (c. 73° F.), it is necessary to reduce the oxygen level in the package sauce powder to 2 percent or less.

PRODUCT EVALUATION

Explosion puffed half-segments make excellent juice-type pies having pleasing flavor and appearance (Figure 5). A suggested procedure used to prepare a 9-inch pie is given below:

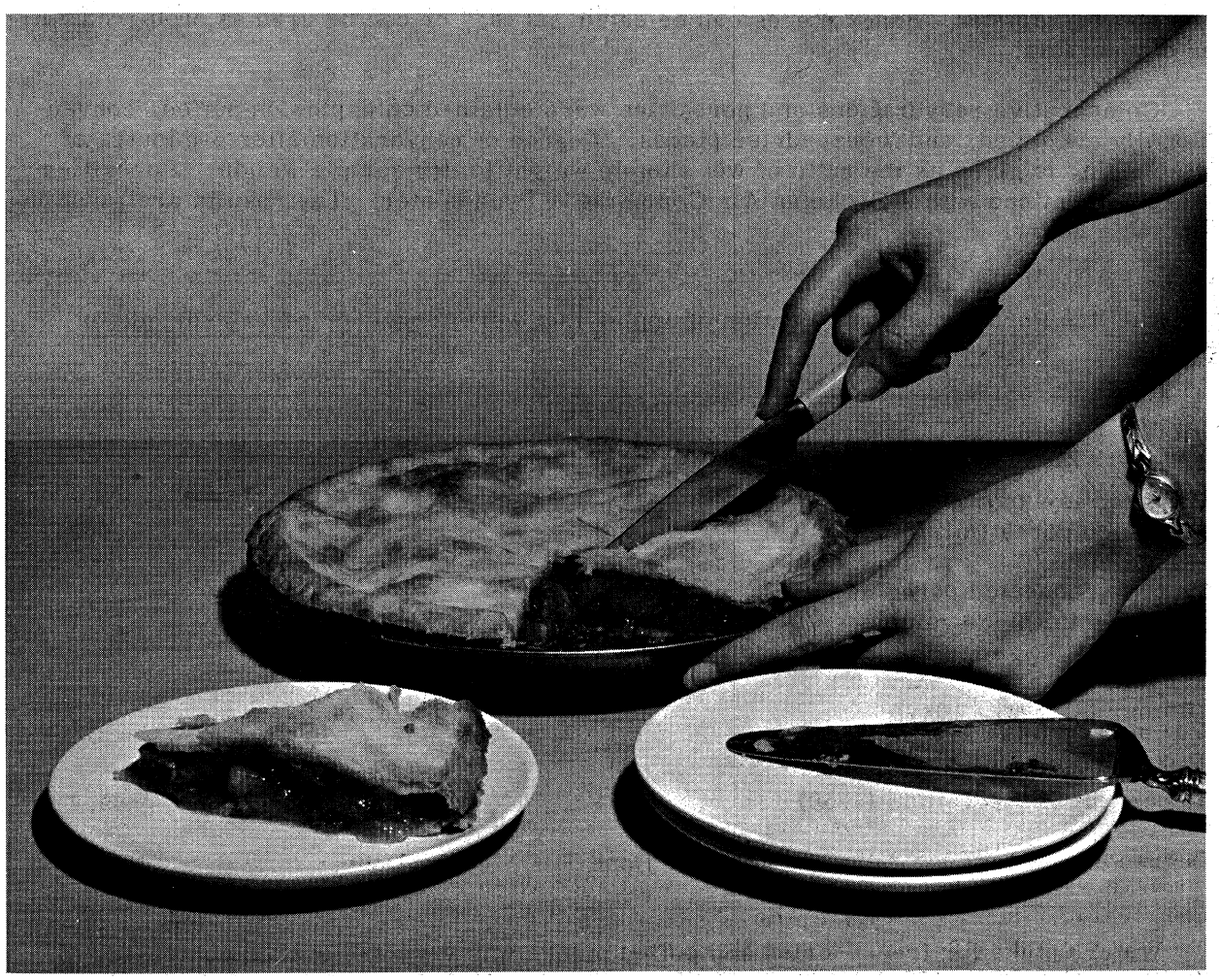

Figure 5. Juice-type apple pie.

1. Combine contents of can (3-1/2 oz.) with 3-1/4 cups boiling water and boil 5-6 minutes. Drain liquid from apples.

2. Combine 3 tablespoons pie-type starch* with 3/4 cup sugar and mix thoroughly.

3. Add the sugar-starch mixture to the liquid from the apples and cook until the liquid becomes thick and clear. (Add spices and 1 tablespoon of lemon juice if desired.) Add the apple pieces to the sugar-starch solution.

4. While this is cooling prepare pie shell.

5. Fill the pie shell and bake at 425° until crust is brown (about 15-20 minutes).

Rehydrated apple yield on baking: 7:1.

A flavorful compote can be made by boiling the puffed pieces in sugar-containing water for about 5 minutes. Snack pieces can be eaten "as is," or can be used as an ingredient in dry cereals.

Comparative rehydrations and porosities were obtained on explosion-puffed, conventionally air-dried, and freeze-dried pieces. Degree of rehydration after 6 minutes of simmering is given as the ratio of wet sample weight to dry sample weight. Porosities were determined with a Beckman Air Comparison Pycnometer. The results are given in the table below.

TABLE 1. Porosity and rehydration of apples that were freeze-dried, air-dried, or explosion-puffed.

Property	Freeze-dried	Explosion-puffed	Conventional air-dried
Porosity as surface-connected pores (ml./g.)	6.2	1.3	0.21
Surface-connected pores as percent total piece volume	88.2	61.5	10.7
Rehydration ratio-6 min. simmer (g. wet/g. dry)	5.61	4.44	3.23
Rehydration-6min. - as percent of theoretical (6.50)	86.3	68.3	49.7
Degree of cooking	Done	Done	Not Done

Water uptake for freeze-dried and puffed pieces was very rapid when contrasted to the extremely slow rehydration of conventionally dried pieces. The difference is directly related to the amount of surface-connected pores; hence, explosive puffing greatly improves rehydration rates.

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*For example, American Maize Co. Hi-Gloss 400; Corn Products "Snow Flake" No. 4828; National Starch & Chemical Corp. Clearjel 51-6016, or equivalent.

COST

A plant producing explosion-puffed apples could use the equipment advantageously for other commodities. Cost estimates for carrots (15) and potatoes (16) have shown that explosion-puffed products cost very little more than conventionally dried. There is nothing to indicate that the same would not be true for apple pieces.

ACKNOWLEDGMENTS

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