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HEAT PROCESSING CHARACTERISTICS OF FRESH CUCUMBER PICKLE PRODUCTS

III. Heating Rates of Slices

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SLICED FRESH CUCUMBER PRODUCTS, known by such familiar names as bread and butter pickles, cross cuts, slices, or chips, are preserved by a pasteurization process. The heating characteristics of the product are an important factor in determining the pasteurization time and, consequently, the size of pasteurizer needed to satisfy the desired production schedule. This paper reports the results of a series of studies to determine the effect of the major processing variables on the heating characteristics of fresh cucumber slices.

Slices are produced by cutting with high-speed knives No. 3 cucumbers (1½ to 2 in. diameter) perpendicular to the long axis of the fruit. The thickness of cut can be varied by changing the speed of the cucumber past the knives, the knife speed, or both. In commercial practice, thicknesses usually range from ⅛ to ¼ in., but exceptions can be found above and below these values. Apart from variations in the spicing, there are two types of covering liquor—a salt-acid brine or a sugar-salt-acid syrup.

Sliced pickle products made using a salt-acid brine present fewer manufacturing problems than sweet-sliced pickles, which require a sugar-salt-acid syrup, because the problems are primarily associated with the behavior of the sugar syrup. If the syrup concentration is high, the heating rate of the product may be drastically reduced and several months may be required for the contents of the jar to equilibrate because of stratification (5).

Too, sugar-salt-acid solutions are corrosive and difficult to remove from equipment. When an overflow syruper is used, syrup adheres to the outside of the jars. Subsequent washing of the jars flushes this

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sugar into the plant effluent where each pound of sugar represents a pound of BOD (biochemical oxygen demand).

Many of these syrup-related problems could be at least partially eliminated by changes in manufacturing procedure. The ideal slice-manufacturing procedure would be a continuous operation. Graded, washed, and blanched cucumbers would be fed into cutting machines. After cutting, imperfect slices would be removed as the product passed over a vibrating screen and the sound slices conveyed directly to an automatic filling machine. This machine would fill each jar with a pre-determined weight of slices. The jars would be filled with the covering liquor in a vacuum syruping machine, capped, and rotated or agitated to insure mixing both before and after pasteurization. The jars then would be stacked in the warehouse upside down and turned right side up on removal to speed equalization.

In many pickle manufacturing plants, slice manufacture is still predominantly a batch or, at best, a semi-continuous operation. The method described by Etchells and Jones (3) is still in use. This involves soaking the cucumber slices from several hours to overnight in a 30° salometer (7.9 percent) brine. Other manufactures simply hold cut slices in a weak salt brine, 3 to 5 percent, from the time the slices are cut until they are ready to be packed.

Controlling the weight of slices in a container is a major problem because the put-in weight affects both the rate of heating and the final sugar and acid level. Placing the syrup or brine in the jar prior to adding slices, called pre-brining or pre-syruping, may be used as an aid in controlling fill. With this method, cucumber slices are added to the pre-syruped jar until the syrup reaches a predetermined distance, usually about 1 inch, from the top of the jar. The final liquid level is obtained by overflow filling of syrup or water followed by head spacing.

Overflow syruping is an expensive operation because significant quantities of syrup adhere to the jar and are wasted. It is possible, by using a more dense syrup, to add the necessary sugar, salt, and acid in the pre-syruping operation and then, after the correct quantity of slices has been added, finish liquid filling with water. Water topping has the advantage of saving sugar and reducing plant effluent BOD. However, the addition of water on top of the syrup insures stratification.

The process variables examined in this study are soaking, covering liquor temperature, holding time between syruping and pasteurization, covering liquor composition, fill ratio, water topping, and container size. The results have been evaluated in terms of the heating rate (f_h)[1] and lag factor (j).

The heating characteristics of sliced pickle products have received very little attention from researchers. Esselen *et al.* (1) reported heating-rate data for soaked slices in a 4.5 percent acid, 30 percent sucrose syrup in 32-oz. jars and Esselen and Anderson (2) reported data for additional jar sizes. Townsend *et al.* (10) have presented heating rate coefficients for some jar sizes used by pickle manufacturers, whereby known data from one jar size can be used to predict heating characteristics of other jar sizes, thus avoiding the necessity of separate heat penetration measurements.

EXPERIMENTAL

Most of the slice packs were prepared in the laboratory according to the following standard procedure: The cucumbers were cut on a hand-operated slicing machine to thicknesses of 3/16, 7/32, or ¼ in., depending on the test. They were then packed by hand into the jars to the desired fill ratio, covered with brine or syrup at 130-140°F., closed, and placed immediately in a water bath held at 180°F. Exceptions to this standard procedure are noted under the appropriate test. A few tests were run on commercially packed jars.

The standard sweet liquor was 51 percent sucrose—4.0 percent salt—2.8 percent acetic acid. The standard brine was 1.4 percent acetic acid—5.0 percent salt. Descriptions of all except the novelty jars are given in the two previous papers (8, 9). The novelty jar specifications are: normal fill, 24 oz.; maximum outside diameter, 3.75 in.; height to top of finish, 7.12 in.; jar weight, 13.6 oz.; thermocouple distance from bottom of jar, 1.4 in. Water bath characteristics, temperature measurement, themocouple placement, and data analysis are described in (9).

RESULTS AND DISCUSSION

Table 1 gives the results of tests to determine the effect of soaking the slices in a 5 percent salt solution before packing and subsequent pasteurization; each item is the average from three jars. The control jars (no soaking) were packed according to the standard procedure.

[1]By definition, a large heating rate (f_h) indicates slow heating and a small heating rate (f_h) rapid heating.

TABLE 1—Effect of soaking on sweet pickle slices, ¼-in thick, 0.62 fill ratio, 1956

Heating characteristics	Treatment	JAR					
		16-oz. cylinder	16-oz. vege-table	22-oz. cylinder	24-oz. novelty	28-oz. vege-table	32-oz. regular
Lag factor, j	Not soaked	1.34	1.31	1.12	1.14	1.18	1.31
	Soaked	1.50	1.60	1.36	1.48	1.46	1.43
Heating rate, f_h, min.	Not soaked	32.8	32.6	35.6	36.3	53.3	45.4
	Soaked	32.5	30.2	33.2	33.2	48.3	43.8

The jars with soaked slices consisted of one set of six jars (one for each jar size) containing slices soaked for 3½ hours and two sets of six jars each containing slices soaked for 16 hours. These three sets were combined and treated in the analysis of the data as a single soaking treatment of three replications.

Analysis of the data shows that the lag factor, j, although not significantly different among jars, exhibits a highly significant difference between treatments. By contrast, there is no significant difference in the heating rates between treatments, but the difference is highly significant among jars. The 28-oz. vegetable and 32-oz. regular jars have heating rates significantly different from all other jars and from each other. If the lag factor increases and the heating rate remains constant, then, unless the process is increased, the spoilage fraction in jars of soaked slices will be greater. Because soaking provides a favorable environment for the development of some bacteria, the initial microbial load is greater.

The results of a soaking test, where a 30 percent sucrose concentration was used, are shown in Table 2. This soaking treatment caused no significant difference in either heating rate or lag factor. This result should be contrasted with the results of the previous soaking test with the heavier syrup (Table 1). These data serve to emphasize the fact that results based on one syrup concentration cannot necessarily be applied to other syrup concentrations.

One test was made on sweet slices to compare the heating characteristics of slices covered with the standard sweet liquor to those of slices covered with liquor of the same sucrose concentration but without salt or acid. The purpose of the test was to determine

TABLE 2—Effect of soaking on sweet pickle slices, 30 percent sucrose syrup, ¼-in. slices, 0.62 fill ratio, room temperature brine, 1957

Jar	No. jars in test	Soaking period	Lag factor, j				Heating rate, f_h, min.			
			Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
16-oz. vegetable	6	None	1.06	0.81	1.28	0.20	26.9	25.2	29.0	2.1
	6	Overnight	1.08	0.72	1.28		28.3	25.2	29.2	
32-oz.	6	None	1.36	1.19	1.56	0.15	33.4	28.0	41.0	4.8
	4	Overnight	1.33	1.20	1.59		31.6	26.8	34.6	

whether some short-cuts could be made in the heating rate studies by not having to prepare the more complicated sucrose-salt-acid liquor. Without the acid, such a pack will not, of course, be preserved at the low heat treatments used in fresh cucumber production. Table 3 gives the heating characteristics. No significant differences between the covering liquors was found.

TABLE 3—Effect of absence of salt and acid in the covering liquor on sweet pickle slices, ¼-in. thick, 16-oz. vegetable jar, 30-min. hold, 1957

Covering liquor	No jars in test	Lag factor, j				Heating rate, f_h, min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
Standard sweet.......	6	1.25	1.11	1.42	0.17	28.1	23.6	31.0	3.1
50% sucrose only.....	6	1.17	0.99	1.53		31.0	27.2	36.4	

Table 4 shows the effect on heating characteristics of a lower initial temperature of the covering liquor and a 30-min. delay between addition of the liquor and the beginning of the heat treatment. This situation can arise in commercial practice if jars are prebrined and if a jar happens to be delayed on its way to the pasteurizer. The differences in average lag factors and heating rates are significant; the smaller lag factor of the hot-filled jars is favorable to a short process time, but the larger heating rate is not. At the end of a 30-minute process, the hot-filled jars were, on the average, at a slightly higher temperature. The value of the process at the end of 35 minutes in the bath was the same for both treatments. The results show that there is nothing gained by adding hot brine, provided there is a holding time. However, see Table 5 for the effect of holding time.

TABLE 4—Effect of covering liquor temperature on sweet pickle slices, ¼-in. thick, 16-oz. vegetable jar, 0.62 fill ratio, 30-min. hold, 1957

Covering liquor temperature, °F.	No. jars in test	Lag factor, j				Heating rate, f_h, min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
76	6	1.25	1.11	1.42	0.09	28.1	23.6	31.0	2.2
140	6	1.13	1.06	1.23		32.7	31.0	34.4	

Table 5 shows the effects of holding time on the heating characteristics (covering liquor initially at room temperature). The increase in lag factor and decrease in heating rate are significant. In this instance, the effects on the value of the process work in opposite directions so that there is no difference in the accumulated lethality at the end of a 35-minute process. This influence of holding time works to the advantage of the manufacturer, when inevitable delays and other production factors cause the holding time to be variable.

TABLE 5—Effect of holding time on sweet pickle slices, 7/32-in. thick, 16-oz. vegetable jars, 0.62 fill ratio, room temperature brine, 1957

Heating characteristic	Holding time, min.	Ave.(*a*)	Min.	Max.
Lag factor, j	0	1.11	1.01	1.27
	5	1.16	1.02	1.47
	30	1.25	1.11	1.42
	120	1.50	1.32	2.02
Heating rate, f_h, min.	0	32.2	26.2	37.4
	5	31.0	26.2	33.6
	30	28.1	23.6	31.0
	120	27.1	22.2	30.4

(*a*) From six jars.

Table 6 shows the effect of a lower sucrose concentration. The lag factor was unchanged, but the heating rate was significantly smaller.

TABLE 6—Effect of covering liquor composition on sweet pickle slices, ¼-in. thick, 16-oz. vegetable jars, room temperature brine, fill ratio 0.62, 1957

Composition percent sucrose-acetic acid-salt	No. jars in test	Lag factor, j				Heating rate, f_h, min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
51—2.8—4.0	6	1.11	1.01	1.27	0.15	32.2	26.2	37.4	3.3
30—4.5—4.0	6	1.06	0.81	1.28		26.9	25.2	29.0	

Table 7 gives the average heating characteristics of sweet slices in 16-oz. cylinder jars as a function of fill ratio. There was no significant difference among lag factors, but there was a significant increase in heating rate with increasing fill ratio. The range of fill ratio tested (0.62 to 0.84) corresponds to a range in product weight from 10 oz. to 13.5 oz. per 16-oz. jar. This variation is not unrealistic because even a well controlled fill weight may have a standard deviation of 1 oz. This increase in heating rate works to the disadvantage of the processor because tight packs have a higher probability of spoiling.

TABLE 7—Effect of fill ratio on sweet pickle slices, ¼-in thick, 16-oz. cylinder jar, 1959

Heating characteristic(a)	Fill ratio				
	0.62	0.66	0.72	0.78	0.84
Lag factor, j	1.53	1.44	1.66	1.67	1.57
Heating rate, f_h, min	31.0	32.9	34.6	36.2	38.3

(a) Average from six jars.

Table 8 gives the results of the water topping tests. Two sucrose concentrations (69 and 50 percent) were tested. The sucrose syrup was added by weight to already packed jars so that, with the addition of 1 oz. (30 ml.) of tap water, the liquid level was at the correct head space. Slices, syrup, and water were all initially at room temperature. Because the slices were cut from extra-large cucumbers, they were cut in half along a diameter before packing. The thermocouple rods used in these tests contained 9 30-gage couples, the junctions of which were spaced ½-in. apart on alternate sides of the rod.

TABLE 8—Effect of water topping on sweet pickle slices, ¼-in. thick, 0.62 fill ratio, 16-oz. cylinder jars, 1961

Liquor composition	Thermo-couple location(a)	Number jars	Heating characteristic, ave.		Equalized percent soluble solids
			j	f_h, min.	
69% sucrose	0.9	5	1.53	35.2	
plus	1.4	5	1.52	36.7	27
1 oz. water	1.9	5	1.40	42.6	
	2.4	5	1.33	42.6	
50% sucrose	0.9	3	1.44	29.2	
plus	1.4	3	1.39	32.2	23
1 oz. water	1.9	3	1.29	32.2	
	0.9	3	1.33	31.7	
50% sucrose	1.4	3	1.21	34.0	19
	1.9	3	1.23	33.2	

(a) Inches from bottom of jar.

The heating rates in the jars with 69 percent sucrose plus 1 oz. of water were significantly larger. It also should be mentioned that many of the curves in the 50 percent-sucrose-plus-1 oz.-of-water and 50 percent-sucrose-only treatments were broken heating curves. Perhaps more important than the increase in heating rate (depending on the initial sucrose concentration) is the possibility of a low pH at the top of the jar. Two hours after adding the 69 percent sucrose plus water topping (after heating and cooling), the sucrose concentration at the top of the jars was 10 percent. If the jars are to be water topped, pH measurements ought to be made of the liquid in the top of the jar at various times during the heat process.

Table 9 includes some miscellaneous data. The first three items listed in the description column deal with commercially packed sweet slices in 16-oz. jars in which the point measured was farther from the bottom than in the laboratory packs. These data compare to some extent with other data for 16-oz. jars; however, among the three treatments, there were no significant differences in lag factor or heating rate.

Table 10 gives the heating characteristics of slices covered with a salt-acid brine in jars of various sizes. Some of these data and a discussion of them have been given in (6). These results may be contrasted with the results for syrup (Table 1).

Table 11 gives the heating characteristics as a function of position

TABLE 9—Heating characteristics of miscellaneous sweet pickle slice packs

Description	No. jars in test	T.C. setting(a)	Fill ratio	Lag factor, j			Heating rate, f_h, min.		
				Ave.	Min.	Max.	Ave.	Min.	Max.
Soaked, 16-oz. cylinder	8	1.7	LP(b)	1.36	1.18	1.58	34.6	29.2	37.6
Soaked, 16-oz. cylinder, 30-min hold	8	1.7	LP(b)	1.42	1.27	1.76	33.2	26.0	40.2
No soaking, 16-oz., cylinder	16	1.7	0.72	1.52	1.31	1.80	39.0	34.2	45.2
Half-gallon	4	1.4	0.62	1.27	1.20	1.39	66.1	63.4	68.5
16-oz. vegetable jar 1956 (unknown prepasteurization treatment)	18	0.6	0.62	1.49	1.23	1.71	33.5	29.1	39.8

(a) Inches above jar bottom.
(b) Line pack from pickle plant.

along the central axis of the jar. The objective was to locate the slowest heating point in the jar. The data showed that in each jar, the point of least lethality was located 0.2 of the total liquid height from the bottom of the jar. This point was used in all tests, in the absence of contrary data on the slowest heating point.

The variations in the heating characteristics of slices are all traceable to variations in manufacturing procedure; however, slow heating results only when stratification takes place. When there is only a small amount of stratification, the heating characteristics of sweetened slices may be only slightly different from brine-packed slices. For

TABLE 10—Heating characteristics of 3/16-in. pickle slices in standard brine, 0.62 fill ratio, 1956

Jar	Number jars in test	Lag factor, j			Heating rate, f_h, min.		
		Ave.	Min.	Max.	Ave.	Min.	Max.
16-oz. cylinder	4	1.34	1.20	1.52	19.6	18.3	21.1
16-oz. vegetable	4	1.32	1.27	1.40	19.2	17.0	22.1
22-oz. cylinder	4	1.36	1.17	1.44	23.3	21.0	24.6
24-oz. novelty	4	1.37	1.19	1.47	21.9	21.2	22.7
28-oz. vegetable	4	1.23	1.10	1.41	21.2	19.8	24.6
32-oz. regular	4	1.24	1.12	1.40	23.5	22.1	25.0

TABLE 11—Heating characteristics in different positions in a jar, standard salt-acid brine, 3/16-in. thick, 0.62 fill ratio, 1956

Heating characteristic(a)	Jar	Position (fractional distance from bottom to top of jar)				
		0.0	0.1	0.2	0.4	0.8
Lag factor, j	22-oz. cylinder...	0.92	1.23	1.12	1.23	1.24
	32-oz regular....	1.06	1.21	1.30	1.20	1.15
Heating rate, f_h, min.	22-oz. cylinder...	19.5	19.2	20.0	19.4	17.0
	32-oz. regular....	24.5	24.1	24.5	20.4	13.6

(a) Averages from two jars.

some cases, however, where severe stratification occurs, conduction heating may take place.

The heating rate of slices in a uniform brine or syrup will be substantially different from that in a stratified syrup. For a 16-oz. cylinder jar, the approximate f_h values are 20 min. for slices in brine, 30 min. in a stratified jar with a low brix syrup and over 40 min. with a high brix syrup. The in-going high sucrose syrup will set up the necessary stratification to block convection more quickly than a lower sucrose syrup.

The increase in heating rate which follows from stratification is a function of the osmotic pressure difference across the cell wall. Reducing the osmotic pressure difference, by reducing the pressure outside the cell wall or increasing the pressure inside, should decrease the heating rate. The heating rates of sweet slices reported by Esselen *et al.* (1) and Esselen and Anderson (2) are closer to the heating rates of brine-packed slices than to the heating rates of syrup-packed slices reported in this study. The slices in their tests were held overnight in a 30° salometer (7.9 percent) brine, then packed in a 30 percent sucrose syrup with no salt. Since the calculated osmotic pressures (4) inside and outside the cell wall are approximately equal, presumably there was little net water exchange between the syrup and the cucumber slices, and, therefore, little stratification. A lack of stratification can explain their small f_h values, since it has been shown (7) that the difference in heating rate between a 50 percent sucrose syrup and water is small if there is no stratification.

SUMMARY

These studies of the heating characteristics of sliced fresh cucumber pickles have shown:

1. Increased lag factor for soaked slices when the covering liquor was 50 percent sucrose. However, soaking the slices caused no significant changes in lag factor or heating rate when the sucrose concentration was 30 percent.
2. The combination of covering liquor at room temperature and a 30-minute delay before processing resulted in changes in both lag factor and heating rate, but not in the process value.
3. Holding time had a significant influence on both lag factor and heating rate, but no net effect on process value.
4. An increase in fill ratio caused an increase in heating rate.
5. Depending on the sucrose concentration, water topping caused significant changes in the heating rates.

Each of the above findings is valid only under some processing conditions. There are important departures from these general results depending on jar size, initial temperature of the covering liquor, fill ratio, soaking treatment and liquor composition. A final recommendation is to test each particular pack to insure against some unexpected deviation from the anticipated heating rate.

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