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HEAT PROCESSING CHARACTERISTICS OF FRESH CUCUMBER PICKLE PRODUCTS

II. Heating Rates of Whole Pickles

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THIS REPORT, covering whole pickles only, is the second of a series treating the heating characteristics of fresh cucumber pickle products. Because of the large number of possible products, only a limited number were tested; however, the important variables that affect heating characteristics have been examined; namely, variation in jar size and nature of the covering liquor.

Whole pickles constitute the largest fresh cucumber pickle item and therefore have received considerable research attention (1, 2, 3, 4, 5). The whole pickle product, whether sweet or sour, is one of the easiest products to pasteurize from rate of heating point of view; however, certain sections of the industry are still troubled with spoilage of this product.

It is the purpose of this study to develop additional knowledge regarding the heating characteristics of whole pickle products as affected by commonly encountered variables in the hope that this will provide the knowledge which will make possible a more rational pickle pasteurization process design.

EXPERIMENTAL

Jars chosen for this study are representative of those used for actual pickle packs. (The specifications of jars used are given in Table 1.) The cucumbers used in the laboratory packs were washed for 5 minutes in a tumble-action washing machine, blanched for 5 minutes in 150°F water, packed by hand into the jars to a specified weight, covered with 135°F brine (1.4% acetic acid, 4.0% salt, unless otherwise specified), sealed and heat processed in a water bath.

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TABLE 1—Container dimensions

Name	Normal fill oz.(a)	Outside diameter in.	Height to top of finish, in.	Jar weight, oz.	Thermocouple distance from bottom of jar, in.
Vegetable jar (No. 303)	16	3.00	4.75	7.1	0.9
Cylinder	16	2.88	5.50	9.1	1.0
Cylinder	22	3.00	7.25	12.9	1.4
Regular quart(*b*)	32	3.62	7.12	13.1	1.3
Regular ½ gallon	64	4.88	8.60	23.5	1.3
Regular gallon	128	6.31	10.0	39.5	1.7

(a) Overflow capacity about ½ oz. more.
(*b*) Newer, square-shouldered quarts may give different results.

Water bath temperature control and temperature measuring equipment have been previously described (7). Commercially packed jars (line packs) were prepared by a procedure that did not differ appreciably from the routine described above.

RESULTS AND DISCUSSION

The entire analysis of the heating data involves a discussion of heating rate, f_h, and lag factor, j, obtained by standard methods discussed in the first paper of this series (7).

The results of a test comparing the heating characteristics of No. 1 pickles (less than 1 1/16-in. diameter) in 16-oz. vegetable and 16-oz. cylinder jars are given in Table 2; the 16-oz. cylinder is a slightly taller jar with smaller diameter. No significant difference was found between the heating rates or lag factors of this product in these two types of jars; however, the comparison may not be strictly justified because the data for 16-oz. cylinder jars were from a line pack and

TABLE 2—Comparison of heating characteristics in two different 16-oz. jar shapes (whole No. 1 cucumbers in brine, 1956)

Jar type	No. jars in test	Fill ratio	Lag factor (j)				Heating rate (f_h) min.			
			Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
16-oz. cyl.	16	LP(*a*)	1.22	1.06	1.45	0.14	17.0	13.6	20.3	1.59
16-oz. veg.	6	0.62	1.14	0.89	1.34		17.6	15.9	19.6	

(*a*) Line pack

the 16-oz. vegetable jars were hand packed with a fill ratio[1] of 0.62 which is believed to be close to the line pack fill ratio.

Small whole pickles may be packed in a sweet liquor or in brine; the products are known respectively as sweet gherkins and midget dills. A comparison of the heating characteristics of these two products in jars of the same geometry is given in Table 3. No significant difference was found between the heating rates or lag factors for the two packs.

TABLE 3—Effect of covering liquor on heating characteristics of whole No. 1 cucumbers, syrup vs. brine, (line packs, 16-oz. cylinder jars, 1957)

Liquor	No. jars in test	Lag factor (j)				Heating rate (f_h) min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
Brine........	8	1.13	1.00	1.44	0.16	17.5	13.8	21.8	3.01
Syrup........	15	1.17	1.04	1.30	0.09	17.6	13.8	20.7	1.5

The data from these two tests can be used to illustrate one of the perennial problems of the pickle packer: whether to base temperature reached (or desired) in the heat process on the brine temperature or on the temperature inside the cucumber. The thermocouple location, whether inside or outside a cucumber, was determined after the tests (16 jars were examined, 8 of the brine packs and 8 of the syrup packs). In 10 cases (five from each test) the thermocouple happened to be inside a cucumber and in 6 cases outside (approximately in the same proportion as cucumber volume to brine volume). These data were analyzed on the basis of location of the thermocouple, and the heating rates were found to be significantly different at the 1 percent level, the heating rate (f_h) inside the cucumber being larger. The lag factor for a point inside a cucumber was larger than for a point outside, but the difference was not significant. Figure 1 shows two curves for a point in the region of the slowest heating point in the jar based on average f_h's and j's, one curve inside a cucumber and one outside a cucumber.

Suppose a heating process is being monitored by keeping a record of temperatures reached in the jar after a fixed time in the pasteurizer. If all the measurements are made in the brine (outside the pickle), then the average temperature measured will be higher than the true temperature inside the cucumber. If no effort is made to distinguish

[1]Ratio of product weight in ounces to jar capacity in ounces.

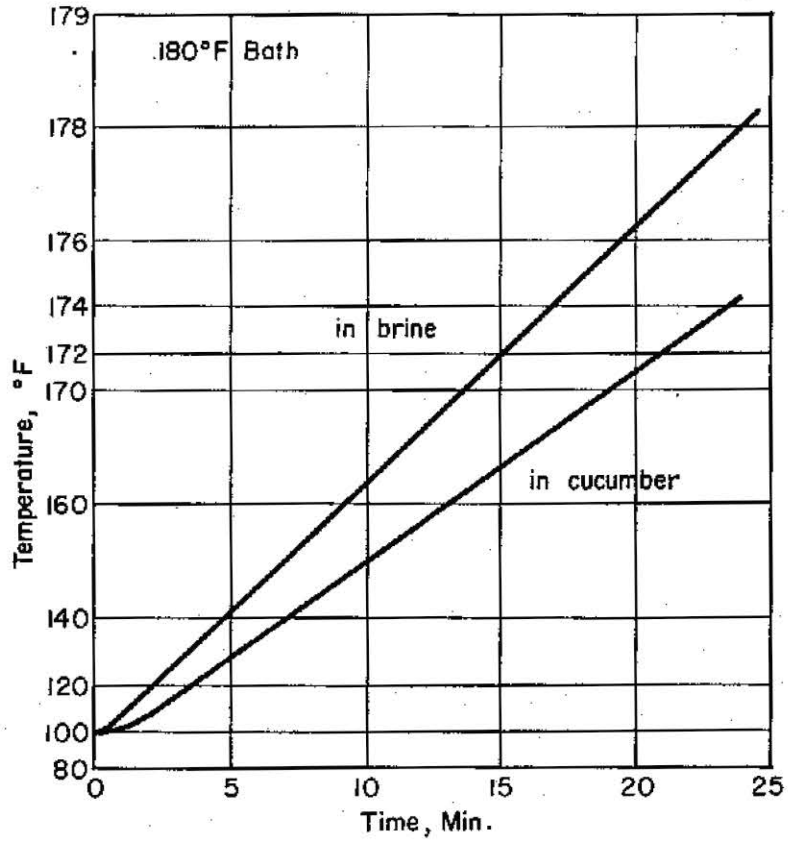

Fig. 1. Temperatures in jars of whole pickles in the vicinity of the point of slowest heating.

between readings made inside and outside a pickle, then the resulting measured temperatures will have an average higher than the pickle temperature, but lower than the brine temperature; moreover, these data will have a larger spread than temperatures measured in brine only or in pickles only.

Table 4 gives the heating characteristics of presumably identical groups of jars packed in the plant at two different times on the same day. The data show a highly significant increase in the heating rate (f_h), although not in lag factor (j), for the jars taken off the line at 11:00 a.m. compared to those at 9:00 a.m. Since both packs were taken from the same packing line, and no effort was made to weigh the product, is it not known if there was a difference in fill ratio. It is known that

TABLE 4—Heating characteristics of whole No. 1 cucumbers in brine at two different times, (line packs, 16-oz. cylinder, 1956)

Time	No. jars in test	Lag factor (j)				Heating rate (f_h) min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
9:00 a.m.(*a*) .	16	1.22	1.06	1.45	0.14	17.0	13.6	20.3	1.59
11:00 a.m.	12	1.19	0.98	1.41	0.15	19.4	17.1	21.8	1.73

(*a*) Same data as Table 2, line 1.

individual packers vary in packing rate from day to day and from one time of day to another.

Conceivably, differential packing rates are achieved at the expense of packing ratio, and the jars in the 11:00 a.m. test were, on the average, more tightly packed, a condition which is believed to cause the product to heat more slowly, (f_h is larger). If such a condition exists, then an additional burden is placed on the processor who does not control the fill ratio closely. This possible variation in fill ratio must be compensated for by longer processing times (with correspondingly lower pasteurizer output), or else spoilage fractions will be higher than usual.

The results of tests on whole No. 2 cucumbers performed in 1956, 1957, and 1958 are given in Table 5. The 1957 and 1958 tests were both made in the laboratory at the same 0.66 fill ratio and there was no significant difference in the heating characteristics. The 1956 jars were line packed and were probably closer to a 20-oz., or 0.62 fill ratio; they exhibited a significantly faster heating rate.

The 1957 results in Table 5 are combined results of a test of the effect of acid strengths of 1.15 percent and 1.4 percent on the heating characteristics. No significant difference was found between the heating rates or lag factors; therefore, the results from the two 7-jar groups were combined.

TABLE 5—Heating characteristics of whole No. 2 brine packed cucumbers, (32-oz. regular jars)

Year	No. jars in test	Fill ratio	Lag factor (j)				Heating rate (f_h) min.			
			Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
1956. . .	20	LP	1.06	0.85	1.39	0.12	20.9	13.8	28.4	4.24
1957. . .	(*a*)14	0.66	1.21	0.81	1.51	0.25	27.8	20.4	31.0	2.82
1958. . .	(*b*)13	0.66	1.25	0.93	1.43	0.16	25.0	21.2	28.9	2.39

(*a*) Seven jars each at two acid strengths 1.4% and 1.15% acid; results combined.
(*b*) Three bath temperatures (160, 180, 200°F); results combined.

The 1958 test (Table 5) was a test in which, for reasons other than determining heating rates, the jars were processed at three different temperatures, 160, 180, and 200°F. No significant difference was found in heating rates or lag factors among the three different temperatures. However, if the two broken heating curves (one at 160°F and one at 180°F) are eliminated from the analysis, then the analysis shows the heating rate at 200°F to be significantly faster than at the two lower temperatures. This trend is in agreement with previous findings for spear products (7). The data shown in Table 6 lend support to this finding of a variation in heating rate with bath temperature (6).

TABLE 6—Heating characteristics of whole cucumbers in brine at three bath temperatures (fill ratio 0.66, 32-oz. regular, thermocouple location 0.5.-in. from bottom, 1959)

Bath temperature, °F	No. jars in test	Mean lag factor, (j)	Mean heating rate, (f_h) min.
180	5	0.81	22.1
195	5	0.93	20.4
211	5	0.92	18.5

An analysis of variance of these data shows a significant difference among the heating rates, but not among lag factors. The data in Table 6 are for a fill ratio of 0.66, the same ratio as the 1957 and 1958 data in Table 5, but the thermocouples were located at 0.5-in. from the bottom, closer to the bottom than was the case for the Table 5 data.

Table 7 gives the heating characteristics of whole No. 2 cucumbers packed in brine in ½-gallon and gallon jars.

Table 8 is a summary of data obtained over the 3-year period 1956-1958. (Data are taken from Tables 1 through 5). Although

TABLE 7—Heating characteristics of whole No. 2 cucumbers packed in brine (fill ratio 0.62, 1957)

Jar	No. jars in test	Lag factor (j)				Heating rate (f_h) min.			
		Ave.	Min.	Max.	Std. dev.	Ave.	Min.	Max.	Std. dev.
½ gallon.....	8	1.10	0.93	1.36	0.16	33.7	30.8	37.6	2.48
Gallon.......	4	1.19	0.99	1.32	0.14	38.2	37.0	39.6	1.14

TABLE 8—Average heating rates and lag factors for whole cucumbers packed in brine

Jar type	No. of jars	Fill ratio	Average lag factor (j)	Average heating rate, (f_h) min.
16-oz. cyl...	16	LP	1.22	17.0
16-oz. cyl...	12	LP	1.19	19.4
16-oz. cyl...	8	LP	1.13	17.5
16-oz. veg...	6	0.62	1.14	17.6
32-oz. reg...	20	LP	1.06	20.9
32-oz. reg...	14	0.66	1.01	27.8
32-oz. reg...	13	0.66	1.25	25.0
½ gallon....	8	0.62	1.10	33.7
Gallon......	4	0.62	1.19	38.2

whole products have been discussed in many published articles, almost all the work has been done on quart jars of pickles.

As a first approach to the understanding of the heating characteristics of whole pickles, consider Fig. 2 in which are plotted all the average heating rates, except that for sweet gherkins, as a function of jar volume. No attempt was made to differentiate between cucumber sizes, different jar geometries for the same jar volume, different brine acidity or different fill ratios.

The dependence of heating rate on jar size is clearly non-linear so that in designing a process for a half-gallon pack, for instance, it is not necessary to double the heating time previously used for a similar quart pack. No obvious relationship is exhibited between the lag factor (j) and jar volume; therefore, an average lag factor can be used for all jar sizes with reasonable accuracy.

For a first approximation of the heating-rate dependence law, one may consider that the more surface available for heat transfer, the faster the jar will heat and that the more liquid to be heated, the longer the heating period. Figure 3 is a plot of the heating rates as a function of surface-to-volume ratio. This curve gives an approximation of the expected heating rate in any other size container in the range studied. There are significant departures from this suggested heating rate dependence that cannot be explained except by a more detailed knowledge of the factors that determine the rate of heating of particulate food products.

The data in Fig. 3 were compared with the results reported by Esselen and Anderson (3). Heating rates, f_h, and lag factors, j, were approximately the same; however, the "whole fresh dill pickle" heating data reported by Esselen and Anderson did not show as much jar-size effect as found in the present study, but the "whole genuine dill pickle" results were nearly the same. Differences between fill ratio, thermocouple position, and other variables could account for the differences in heating rates between studies.

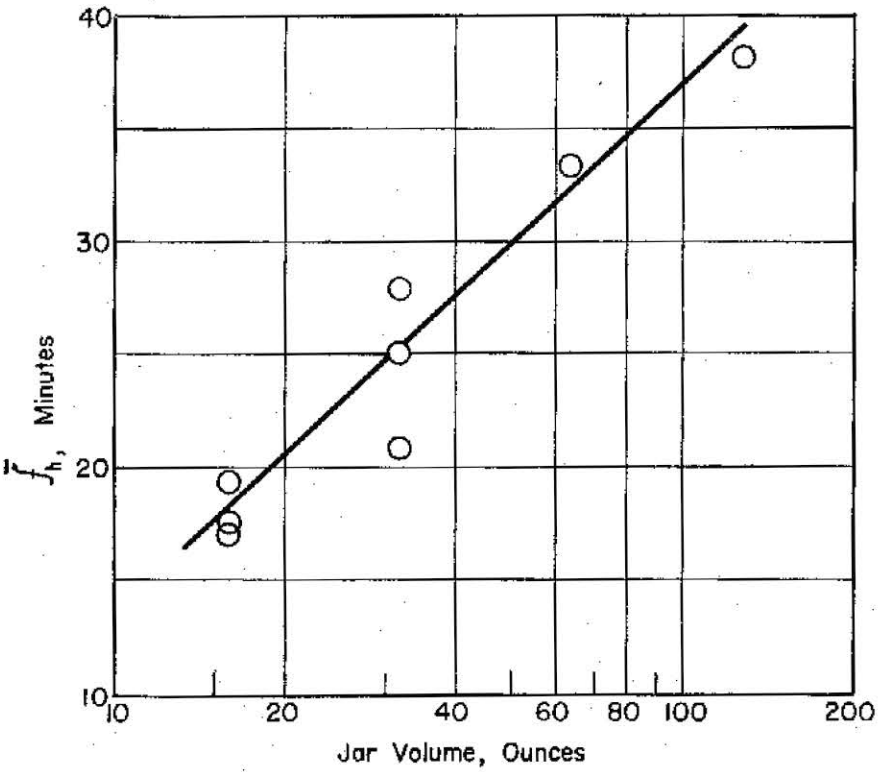

Fig. 2. Heating rate as a function of jar volume.

The variation in heating rate with jar size for convection heating products has been treated theoretically by Schultz and Olson (8); however, the data of the present study do not fit their predictions (based on a jar parameter including diameter and height) as well as the surface-to-volume plot of Fig. 3. A further discussion of this problem is beyond the scope of this report.

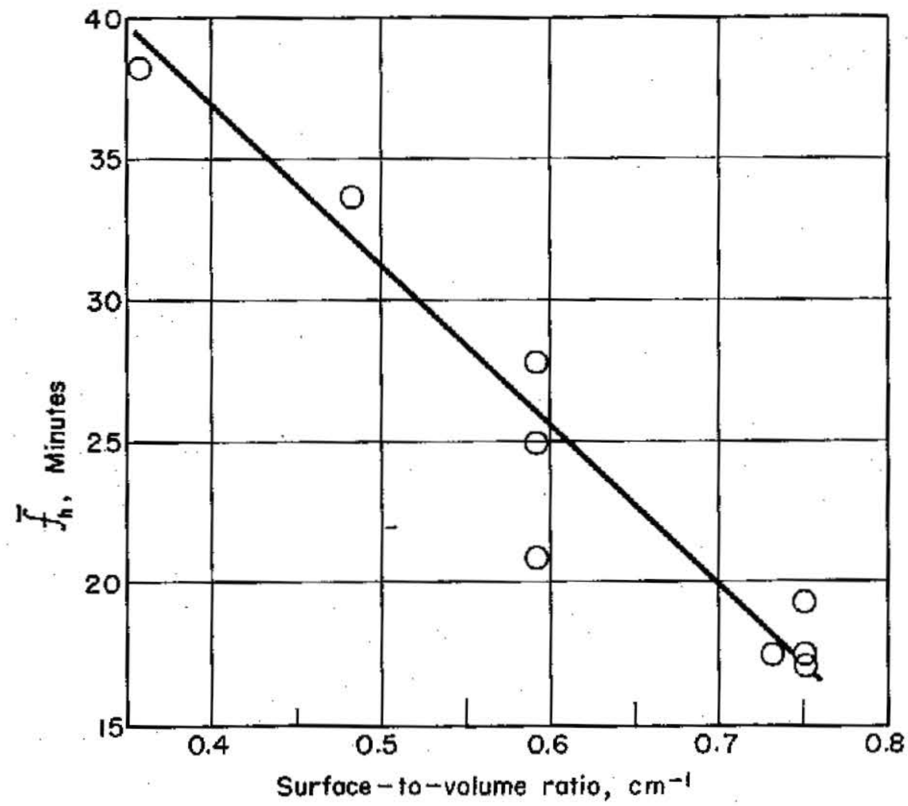

Fig. 3. Heating rate as a function of jar geometry.

SUMMARY

The findings from 3 years' study of heating rates of fresh, whole cucumber pickles can be stated as follows:

1. A curve is given from which an approximation to the heating rate of any particular jar size can be made by knowing the surface-to-volume ratio of the jar.

2. No significant difference was found in the heating characteristics of sweet gherkins and midget dills packed in 16-oz. jars.

3. Differences between liquor temperature and internal cucumber temperature are shown for No. 1 cucumbers packed in 16-oz. jars.

4. Differences in fill ratio are suggested as a source of differences in heating rate for otherwise identical packs; tighter packs appear to heat more slowly.

5. No significant difference in heating characteristics was found between two acid strengths of 1.4 percent and 1.15 percent.

6. A significant difference in heating characteristics was found for quart jars processed at temperatures in the range 180°F to 211°F.

Results 2 and 4 for whole cucumbers should be contrasted with results of similar tests for spear products (7). If a syrup is used instead of brine for a spear product, there will be a marked increase in heating rate (f_h), probably attributable to the fact that in a cut cucumber water leaving the cucumber induces stratification, whereas in a whole pickle this process does not occur to the same extent. Tighter packs in the case of spears have been found to decrease the heating rate slightly, rather than to increase it as is probably the case for whole cucumbers.

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LITERATURE CITED

1. Esselen, W. B., Jr., E. E. Anderson, L. F. Ruder, Jr., and I. J. Pflug, (1951). Pasteurized fresh whole pickles. I. Pasteurization studies. FOOD TECHNOLOGY 5:279-284.
2. ——————, I. S. Fagerson, I. J. Pflug, and E. E. Anderson, (1952). Pasteurized fresh whole pickles. III. Heat penetration in fresh pack pickles. THE GLASS PACKER. 31(3):175-178, 201.
3. ——————, and E. E. Anderson, (1957). The pasteurization of pickles. THE GLASS PACKER. 36(2):46-50.
4. Etchells, J. L., and I. D. Jones, (1943). Mortality of microorganisms during pasteurization of cucumber pickles. FOOD RESEARCH. 8:33-44.
5. ——————, and I. D. Jones, (1944). Procedure for pasteurizing pickle products. THE GLASS PACKER. 23:519-523, 546.
6. Joffe, F. M., (1959). Heat-induced softening in fresh cucumber pickles. Unpublished M.S. thesis, Mich. State Univ.
7. Pflug, I. J., and R. C. Nicholas, (1960). Heat processing characteristics of fresh cucumber pickle products. I. Heating rates of spears. Mich. Agr. Expt. Sta. Quart. Bul. 43:407-414.
8. Schultz, O. T., and F. C. W. Olson, (1938). Thermal processing of canned foods in tin containers. I. Variation of heating rate with can size for products heating by convection. FOOD RESEARCH. 3:647-651.