

BAG-IN-BOX TECHNOLOGY:

Temperature Prediction During Blanching and Cooling of Cucumbers

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ABSTRACT

In the bag-in-box procedure (Fleming et al., 2002), cucumbers are blanched before brining to inactivate the natural microflora and enzymes present in them. In addition, it is desired that the temperature of the cucumbers after blanching and brining should not exceed 32°C (90°F), so as to minimize textural loss due to high temperature. A computer-based, heat transfer program was, therefore, developed to optimize the blanching process. The heat transfer model predicts cucumber temperature during blanching and equilibrium temperature between blanched cucumber and brine/cooling water. Examples of outputs from the program and the influence of cucumber size, initial cucumber temperature, pack-out ratio, and blanching time on the equilibrium temperature attained by blanched cucumber after brining are given in the article.

INTRODUCTION

Cucumbers are blanched in the bag-in-box procedure for fermenting cucumbers as a means of inactivating naturally occurring microorganisms and softening enzymes that may be present on the cucumber surface. Inactivation of the natural microflora is important to prevent growth of gas-forming and other spoilage microorganisms. Inactivation of softening enzymes is important to prevent softening of the cucumbers at the relatively low concentration of salt used.

Evidence indicates that, by far, most microorganisms are located on or near the surface of whole cucumbers (Etchells et al., 1973; Breidt et al., 2000), although some may occasionally occur within the fruit (Samish et al., 1963; Meneley and Stanghellini, 1974). Also, most microbially produced softening enzymes are thought to be located on or near the surface, since washing of cucumbers prior to brining has been shown to reduce enzyme activity and result in firm salt-stock cucumbers (Etchells et al., 1955). It is desired to heat the cucumbers for the minimum amount of time because of energy and other considerations. Therefore, the blanching process must be optimized for it to be commercially applicable to the fermentation and storage of whole cucumbers in bulk containers.

To optimize such a blanching process, we developed a model that describes the heat transfer characteristics of cucumbers during blanching. We currently use the model to predict changes in the temperature of cucumbers during the blanching and cooling stages of this process. The information can be used to predict the equilibrium temperature for various sizes of cucumbers brined at varying pack-out ratios and initial temperatures. Although specific information on equilibrium temperature and blanching time can be derived from the computer model generated, tables or figures of example predictions are provided in this paper. For those interested in obtaining specific predicted values not provided in this paper, such data can be obtained by using the computerized heat transfer model available at our Website (www.ncsu.edu/usda-ars-foodscience).

MATERIALS AND METHODS

A two-dimensional Laplacian equation was used to model the heat transfer characteristics of cucumbers during blanching (Eqn. 1).

$$\rho c \frac{\partial T}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} kr \frac{\partial T}{\partial r} + k \frac{\partial^2 T}{\partial z^2} \quad (1)$$

where:

- T = temperature of cucumbers as a function of position and time (°C);
- t = time(s);
- r = radial coordinate of the point of interest expressed as the distance measured along the radius from the center of the cucumber (m);
- z = axial coordinate of the point of interest expressed as the distance measured along the length from the center of the cucumber (m);
- k = thermal conductivity (W/m K);
- c = specific heat (J/kg K);
- ρ = density (kg/m³).

The initial and boundary conditions to Equation 1 are given by:

$$T = T_o \quad @ t = 0 \quad (2)$$

$$\frac{\partial T}{\partial r} = 0 \quad @ t > 0, r = 0 \quad (3)$$

$$\frac{\partial T}{\partial z} = 0 \quad @ t > 0, z = 0 \quad (4)$$

$$-k \frac{\partial T}{\partial r} = h(T - T_o) \quad @ t > 0, r = R \quad (5)$$

$$-k \frac{\partial T}{\partial z} = h(T - T_o) \quad @ t > 0, z = L/2 \quad (6)$$

where h is the heat transfer coefficient (W/m² K), and R and L are the radius and length (respectively) of cucumbers in meters. More details on the validation of the above equations can be found in Fasina and Fleming (2001).

Cooling of the cucumber after blanching was modeled using energy balance (Eqn. 7). It was assumed that all the heat lost by hot cucumbers is gained by the brine during the cooling process.

$$m_c c_c (T_h - T_f) = m_b c_b (T_f - T_i) \quad (7)$$

where

- c_b = specific heat of brine (J/kg K);
- c_c = specific heat of cucumber (J/kg K);
- m_b = mass of brine (kg);
- m_c = mass of cucumber (kg);
- m_c/m_b = pack-out ratio;
- T_f = final temperatures of cucumber and brine after cooling (°C);
- T_h = average temperature of cucumbers after blanching (°C); and
- T_i = initial temperature of cooling brine (°C).

Use of Model

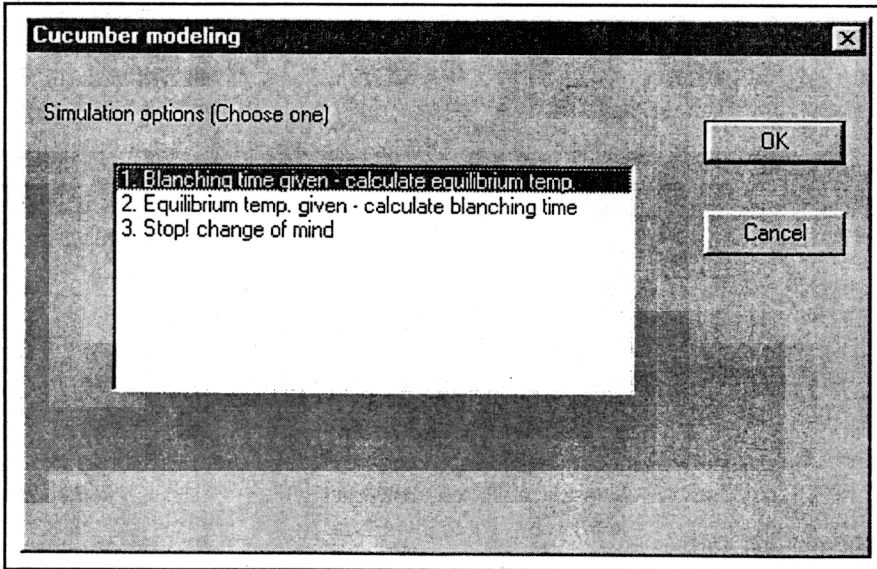


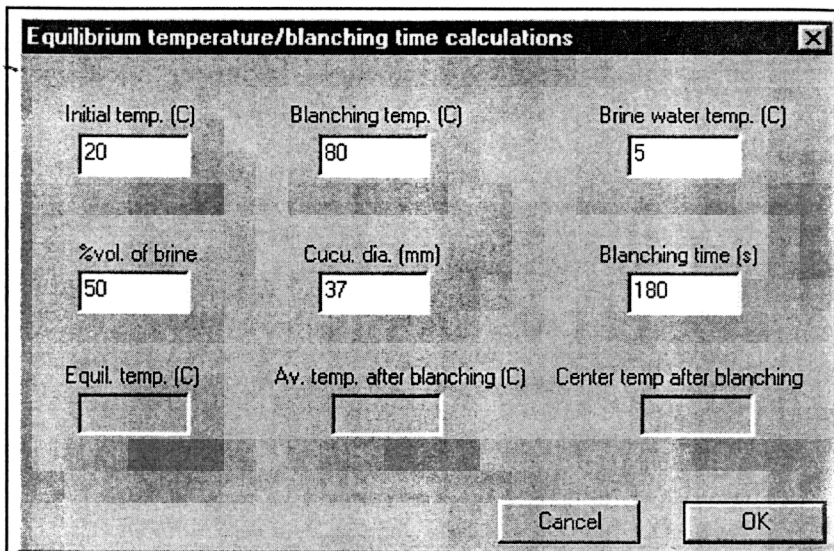
Figure 1. First window in the heat transfer program.

Figure 2. Second window in the heat transfer program. Option a = known blanching time; Option b = known desired equilibrium temperature.

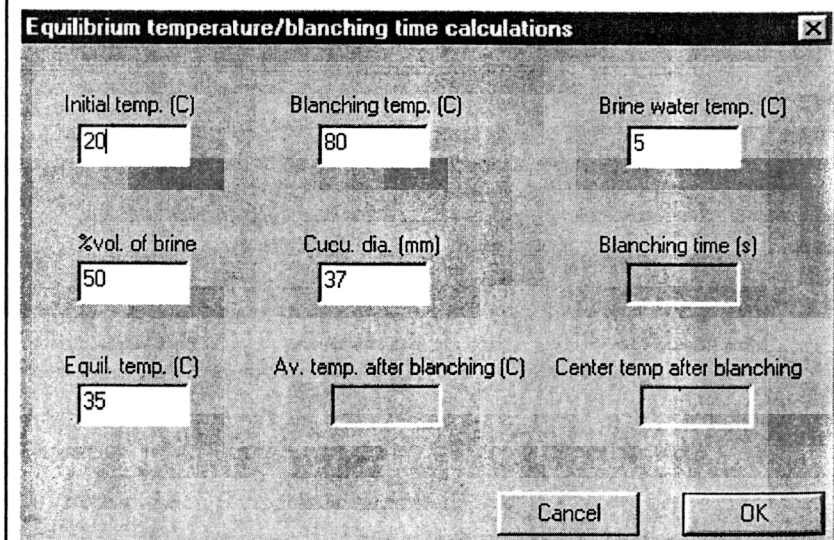
A user-friendly computer program was written and compiled from the above set of equations using FORTRAN language (Compaq Digital Visual Fortran 5.0, Digital Equipment Corporation, Mayard, MA). The program was provided as an executable file (heatcool.exe) that runs on any computer with MS Windows (Windows 95, 98, Me, 2000, and XP) operating system.

A user of the program will double-click on the executable file (heatcool.exe). The window show in Figure 1 will come up. The user has to select one of the two simulation options which are: (a) calculation of equilibrium temperature between brine and blanched cucumber if blanching time is given, or (b) calculation of blanching time for a given equilibrium temperature. The user then inputs the initial cucumber temperature, temperature of the water used for blanching, pack-out ratio, and cucumber size. If option 1 is chosen in Figure 1, the user inputs blanching time (Fig. 2a). The program thereafter calculates the equilibrium temperature of cucumbers after brining, and the average and center temperatures of cucumbers after blanching (example of output is shown in Fig. 3). If option 2 is chosen in Figure 1, the user inputs the desired equilibrium temperature of the cucumbers after brining (Fig. 2b). The program calculates the time required for blanching, and the average and center temperature of the cucumbers after blanching (Fig. 3). Examples of the effects of size, initial cucumber temperature, blanching time, and pack-out ratio on equilibrium temperatures attained by cucumbers after blanching and brining are given in Figures 4 to 9.

For users of the program who are interested in knowing more about temperature profile inside the cucumber fruit during blanching, a tab-delimited file is created on the C drive of the computer at anytime the program is run. The file (outdate.txt), which contains the temperature at any location within the cucumber at the end of the blanching process, can be opened by any spreadsheet software (such as Microsoft Excel). The



(a)



(b)

TEMPERATURE PREDICTION

Equilibrium temperature/blanching time calculations X

Initial temp. (C) <input type="text" value="20.00000"/>	Blanching temp. (C) <input type="text" value="80.00000"/>	Brine water temp. (C) <input type="text" value="5.000000"/>
%vol. of brine <input type="text" value="50.00000"/>	Cucu. dia. (mm) <input type="text" value="37.00000"/>	Blanching time (s) <input type="text" value="180.0000"/>
Equil. temp. (C) <input type="text" value="33.52803"/>	Av. temp. after blanching (C) <input type="text" value="60.05803"/>	Center temp after blanching <input type="text" value="27.49613"/>

(a)

Equilibrium temperature/blanching time calculations X

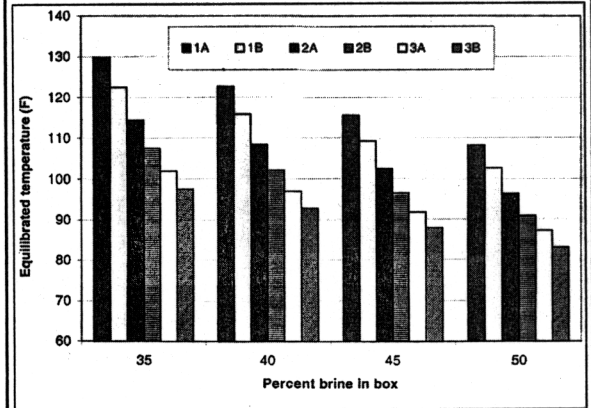
Initial temp. (C) <input type="text" value="20.00000"/>	Blanching temp. (C) <input type="text" value="80.00000"/>	Brine water temp. (C) <input type="text" value="5.000000"/>
%vol. of brine <input type="text" value="50.00000"/>	Cucu. dia. (mm) <input type="text" value="37.00000"/>	Blanching time (s) <input type="text" value="216.0000"/>
Equil. temp. (C) <input type="text" value="35.00000"/>	Av. temp. after blanching (C) <input type="text" value="62.90364"/>	Center temp after blanching <input type="text" value="31.62224"/>

(b)

Figure 3. Third window in the heat transfer software program. Option a = known blanching time; Option b = known desired equilibrium temperature. In each case, the average and center temperatures of the cucumbers after blanching are given.

Figure 5. Equilibrium temperature in the box when cucumbers were blanched for 3 min. Pack-out ratio = 55:45 (cucumber: brine). Effect of initial cucumber temperature. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

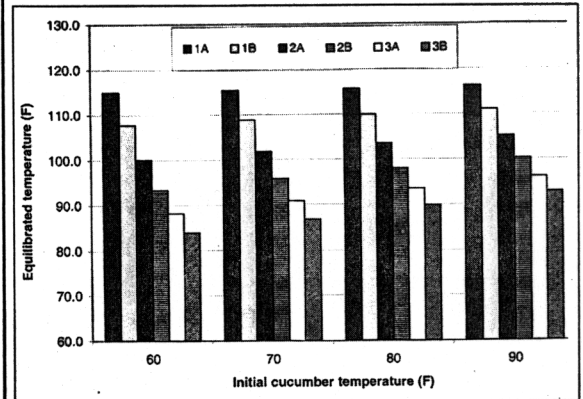
% Brine in box	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
35	129.8	122.4	114.4	107.5	101.9	97.4
40	122.7	115.8	108.5	102.0	96.8	92.7
45	115.5	109.2	102.4	96.5	91.7	87.9
50	108.3	102.5	96.3	90.9	87.2	83.1



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

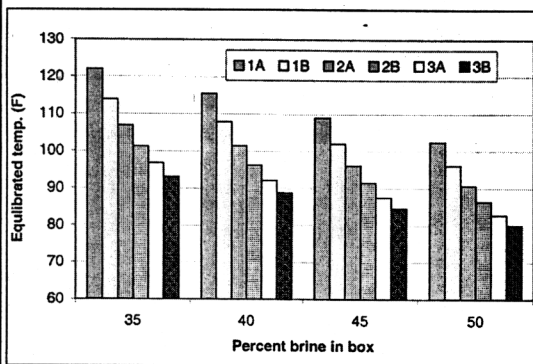
Figure 4. Equilibrium temperature in the box when cucumbers were blanched for 3 min. Initial cucumber temperature = 23°C (73°F). Effect of pack-out ratio. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

Initial cucumber temperature (°F)	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
60	114.9	107.8	100.1	93.4	88.2	83.9
70	115.3	108.8	101.8	95.7	90.8	86.8
80	115.6	109.9	103.5	98.0	93.5	89.9
90	116.2	111.0	105.2	100.1	96.1	92.8



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

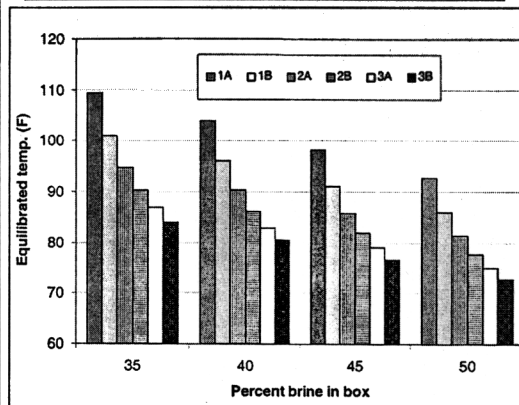
% Brine in box	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
35	122.0	113.9	106.9	101.3	96.8	93.2
40	115.5	108.0	101.5	96.3	92.1	88.9
45	109.0	102.0	96.1	91.4	87.4	84.6
50	102.4	96.1	90.7	86.4	82.8	80.1



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

Figure 6. Equilibrium temperature in the box when cucumbers were blanched for 2 min. Initial cucumber temperature = 23°C (73°F). Effect of pack-out ratio. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

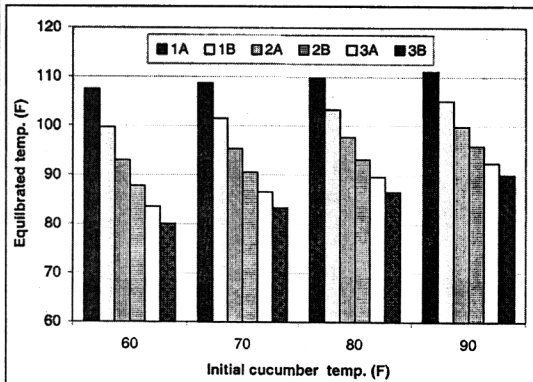
% Brine in box	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
35	109.4	101.0	94.8	90.3	86.9	84.0
40	103.8	96.1	90.3	86.2	82.9	80.4
45	98.2	91.0	85.8	82.0	79.0	76.6
50	92.7	86.0	81.3	77.7	75.0	72.9



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

Figure 8. Equilibrium temperature in the box when cucumbers were blanched for 1 min. Initial cucumber temperature = 23°C (73°F). Effect of pack-out ratio. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

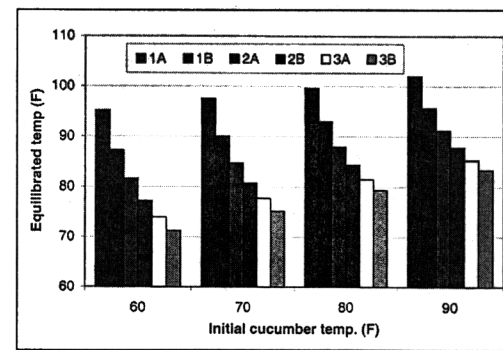
Initial cucumber temperature (°F)	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
60	107.4	99.7	93.0	87.8	83.5	80.1
70	108.7	101.5	95.4	90.5	86.5	83.3
80	109.8	103.3	97.7	93.2	89.6	86.6
90	111.0	105.1	99.9	95.9	92.5	90.0



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

Figure 7. Equilibrium temperature in the box when cucumbers were blanched for 2 min. Pack-out ratio = 55:45 (cucumber:brine). Effect of initial cucumber temperature. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

Initial cucumber temperature (°F)	Cucumber size ¹					
	1A	1B	2A	2B	3A	3B
60	95.2	87.3	81.7	77.2	73.9	71.2
70	97.5	90.1	84.7	80.8	77.7	75.2
80	99.7	93.0	88.0	84.4	81.5	79.3
90	102.0	95.7	91.2	87.8	85.3	83.3



¹It was assumed that the diameter of the cucumber sizes are: 1A = 0.75 inch, 1B = 1.00 inch, 2A = 1.25 inches, 2B = 1.50 inches, 3A = 1.75 inches, 3B = 2.00 inches.

Figure 9. Equilibrium temperature in the box when cucumbers were blanched for 1 min. Pack-out ratio = 55:45 (cucumber:brine). Effect of initial cucumber temperature. Blanch water temperature of 82°C (180°F) and brine/cooling water temperature of 5°C (41°F).

information in this file serves as a guide for us regarding the extent of heating within the cucumber during any given blanching treatment.

RESULTS AND DISCUSSION

The ability to predict equilibrium temperatures of blanched cucumbers and the brine and container in which they are placed may have various applications. In the present case, we wish to know the equilibrium temperature of blanched cucumbers when brined in about 300-gal containers, as in our bag-in-box technology. We prefer that

the equilibrium temperature not exceed 32°C (90°F) to prevent textural loss of the cucumbers. Depending on insulation of the container and other factors, the brined cucumber temperature may remain relatively high for an extended time. Also, temperature affects growth and survival of the lactic acid bacteria culture added to the cover brine. If the temperature is above about 43°C (110°F), the culture may be injured and/or inactivated.

With these points considered, a study of the examples illustrated in Figures 4-9 will serve to indicate blanching times at 82°C (180°F) that will not exceed the maximum preferred equilibration

temperature. For example, from Figure 4, with a pack-out ratio of 45% brine and a cover brine temperature of 5°C (41°F), only size 3B cucumbers could be blanched for 3 min without exceeding the 32°C maximum equilibrated temperature. However, if heated for only 1 min (Fig. 8), the equilibrium temperature of size 2A and larger cucumbers would not exceed 32°C.

We should acknowledge that we do not know the minimum time/temperature that can be used to inactivate microorganisms and softening enzymes on the cucumber surface. This is a subject for future research. It is conceivable that the cucumbers could be cooled to some extent after they leave the blancher and before entering the bag-in-box. The examples in Figures 4-9 assume a cover brine temperature of 5°C, coming into equilibrium with the blanched cucumbers. These and other factors should be considered in developing a commercial-scale system for bag-in-box technology for brine-fermented cucumbers.

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REFERENCES

Breidt, F., Hayes, J. S., and Fleming, H. P. 2000. Reduction of microflora on whole pickling cucumbers by blanching. *J. Food Sci.* 65:1354-1358.

- Etchells, J.L., Bell, T.A., and Jones, I.D. 1955. Studies on the origin of pectinolytic and cellulolytic enzymes in commercial cucumber fermentation. *Food Technol.* 9:14, 16.
- Etchells, J. L., Bell, T. A., Costilow, R. N., Hood, C. E., and Anderson, T. E. 1973. Influence of temperature and humidity on microbial, enzymatic, and physical changes of stored, pickling cucumbers. *Appl. Microbiol.* 26:943-950.
- Fasina, O. O. and Fleming, H. P. 2001. Heat transfer characteristics of cucumbers during blanching. *J. Food Eng.* 47:203-210.
- Fleming, H. P., Humphries, E. G., Fasina, O. O., McFeeters, R. F., Thompson, R. L., and Breidt, Jr., F. 2002. BAG-IN-BOX TECHNOLOGY: Pilot system for process-ready, fermented cucumbers. *Pickle Pak Sci.* VIII (1):1-8.
- Meneley, J. C. and Stanghellini, M. E. 1974. Detection of enteric bacteria within locular tissue of healthy cucumbers. *J. Food Sci.* 39:1267-1268.
- Samish, Z., Etinger-Tulczynka, R. and Bick, M. 1963. The microflora within the tissue of fruits and vegetables. *J. Food Sci.* 28:259-266.

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ABOUT THE COVER:

Bulk storage in brine has been an economic means of extending the processing season of pickling cucumbers since before the 1930's (1). When larger sizes of cucumbers began to constitute a higher proportion of the crop in the 1960's, bloater formation resulted in buoyancy force sufficient to rupture tank heading timbers (2), but purging of CO₂ from the brine reduced bloater damage and buoyancy forces within the tank (3). However, use of high concentrations of salt in brine storage requires washing of the excess from the brine-stock before conversion to finished products, which requires the use of aeration ponds to biodegrade the organic matter (4), but still results in problems in the handling of salt and other non-biodegradable wastes. The use of fiberglass and polyethylene tanks (5) has reduced salt leakage that was prominent with wooden tanks (1-3), but relatively high salt concentrations are still used to serve as insurance against vagaries of nature due to tanks being open to the atmosphere. Closed tanks have been considered by the industry (6), but various factors have resulted in modernized brine yards of open-top, fiberglass and polyethylene tanks and a waste handling system (7). This issue of the journal is devoted largely to summarizing efforts to design and test a pilot system (8) for preserving "process-ready," brined cucumbers with improved quality and reduced wastes, and with intended benefits to the producer and processor of pickling cucumbers.

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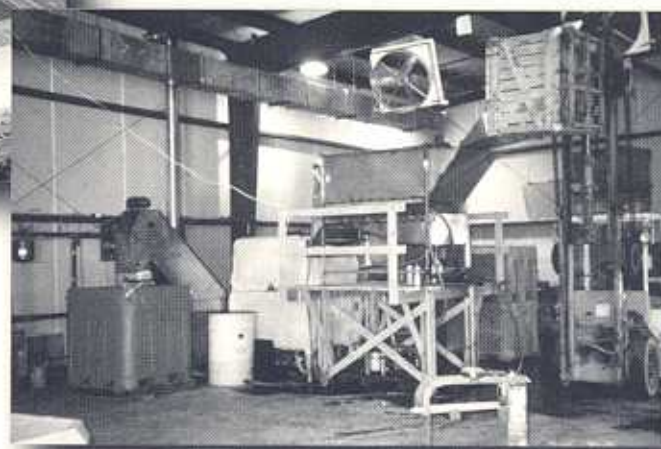
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SCIENCE

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