This research was supported by a
research grant from Pickle Packers
International, Inc., St. Charles, Ill. U.S.A.

*H. P. FLEMING, R. L. THOMPSON, T. A. BELL and R. J. MONROE*
*Food Fermentation Lab, USDA Southern Region, ARS*
*and Departments of Food Science and Statistics*
*North Carolina State University, Raleigh, NC 27607*

# EFFECT OF BRINE DEPTH ON PHYSICAL PROPERTIES OF BRINE-STOCK CUCUMBERS

## ABSTRACT

The effect of brine depth on the quality of brined pickling cucumbers was determined. Brines were maintained at specific and uniform concentrations of dissolved $CO_2$ with either $CO_2$, 68% $CO_2$ in $N_2$, or $N_2$ bubbled through the brines. The extent of bloater damage (hollow cucumbers) varied directly with $CO_2$ concentration and inversely with brine depth. Also, the rate at which cucumbers acquired a cured appearance increased with brine depth. Tests showed that brine depth affected bloater formation by its influence on three variables: $CO_2$ concentration, hydrostatic pressure and buoyancy pressure. In nonpurged fermentations, $CO_2$ retention increased with brine depth. Hydrostatic pressure, which increases with brine depth, caused resistance to bloater formation. Damage caused by buoyancy pressure was greater in freshly brined cucumbers near the top than in lower sections of the tanks. Bloater damage in natural, unpurged fermentations varied because of differences in the combined effects of the three depth-related variables cited above. The study suggested that brine-stock quality would be improved if cucumbers were brined in tanks deeper than those presently used; however, $CO_2$ would have to be removed from the brine and buoyancy pressure would have to be properly distributed.

## INTRODUCTION

PICKLING CUCUMBERS are usually fermented in salt brine of suitable strength in open, cylindrical tanks made of wood. The tanks vary in capacity from about 100–2,000 bushels (4–76 kl), with depths of 5–15 ft (1.5–4.6m) and diameters of 8–16 ft (2.4–4.9m). The pickle industry recently has indicated an increased interest in the use of tanks made of other materials, such as fiberglass, plastics and concrete. Some of these materials will permit, others may necessitate, changes in tank design. The controlled fermentation process, which was recently introduced to the pickle industry (Etchells et al., 1973; Fleming et al., 1973, 1975), is stimulating tank redesign. In the design of fermentation tanks, consideration should be given to the effects of brine depth on quality of the brine-stock cucumbers.

In open-tank fermentations with nonpurged brines, depth is the primary geometric dimension that influences $CO_2$ retention; bloater damage due to increases in depth has been attributed to high retention of $CO_2$ (Etchells et al., 1975). In the controlled fermentation process for brined cucumbers, $CO_2$ is removed from the brine by nitrogen purging, and bloater damage is greatly reduced (Etchells et al., 1973; Fleming et al., 1973, 1975).

The objective of our study was to determine the effects of brine depth on the physical properties of brine-stock cucumbers under laboratory and commercial conditions. Bloater damage and cured appearance were quality factors of primary interest. Because brine depth affects $CO_2$ concentration, hydrostatic pressure and buoyancy pressure, we studied the effects of these three variables on brine-stock quality. In previous studies, the effects of these variables could not be distinguished since $CO_2$ was not uniformly distributed throughout the brine (Etchells et al., 1975). In our present study, we were able to maintain desired and essentially uniform $CO_2$ concentrations by bubbling $CO_2$, $CO_2$-$N_2$ or $N_2$ through the brines. Pilot brining tanks were designed and used for the laboratory studies.

## MATERIALS & METHODS

PICKLING CUCUMBERS of mixed cultivars (primarily Chipper and Explorer) were obtained from a nearby pickle company. Only cucumbers free of visible mold damage and mechanical injury were used. Cucumber sizes used were nos. 2, 3 and 4 (2.7–3.8, 3.8–5.1 and 5.1–5.7 cm-diam, respectively).

The effects of brine depth on brine-stock quality were shown by the following types of experiments:

1. Controlled and natural fermentations in pilot and commercial tanks–$CO_2$ purged from the controlled but not the natural fermentations;
2. Controlled fermentations in pilot tanks and 1-gal jars–brines artificially carbonated to specific and uniform $CO_2$ concentrations.

### Pilot brining tanks

Pilot brining tanks were fabricated from 1 ft diam (29.7-cm i.d.), polyvinyl chloride (PVC) tubing, 8-mm wall thickness (Fig. 1). The bottom of each 8-ft (244 cm) long tube was welded to a 3/8-in. (9.5 mm) thick sheet of PVC. Circular sheets of PVC with about 150 holes (9.4-mm diam) separated each tank into three sections. The section dividers could move vertically in the tank, but support pegs prevented them from pivoting. The top section was headed down with a perforated sheet of PVC, which was secured by blocks bolted inside the tank. Rulers were clipped inside the tops of the tanks to measure changes in the brine level (expressed as expansion volume according to Fleming et al., 1973, 1975). Expansion volume represents gas volume inside the cucumbers and is due to bloater formation. Rubber serum stoppers

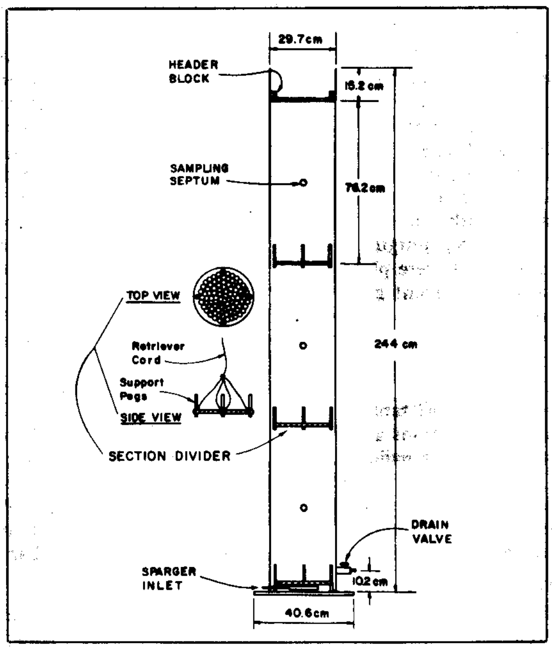

*Fig. 1—Design of pilot-scale brining tanks.*

(15-mm diam) were placed in holes drilled in the tank walls for brine sampling.

The tanks were loaded by lowering one-third of the cucumbers on each section divider with the aid of retriever cords attached to the divider. Brine was pumped into the tank via the drain valve. When the submerged cucumbers became sufficiently flaccid, the header was secured. At the end of brine storage the dividers were raised and unloaded. Because floatation of the cucumbers facilitated this operation, the original brine was replaced with one of slightly greater density (higher NaCl).

### Spargers

Three types of spargers were tested for use in the pilot tanks. The sparger was placed at the bottom of the tank and was connected to a 7-mm o.d., polyethylene inlet tube which protruded through a rubber serum stopper near the bottom of the tank (Fig. 1). This tube was connected to a gas flow meter which in turn was connected to a pressurized gas cylinder of $CO_2$, $N_2$ or a mixture of the two gases. The three types of spargers were:

(1) Porex tubing, $10\mu$ porosity, ultra high molecular weight, polyethylene (Porex Materials Corp., Fairburn, GA), 15-cm long, was plugged with polyethylene at one end and connected to the gas inlet tube at the other end.

(2) Ceramic diffuser tubes, 1- to $2\mu$ pore size, 15-mm o.d., 12-mm i.d., 15-cm long (Coors Porcelain Co., Golden, CO) were sealed to the inlet tube with epoxy cement.

(3) Polyvinyl chloride tubing, Hi-Mol (Carlon Products, Wilton, CT), 1.3-cm o.d., 20 cm long, was drilled with three 1/64 in. (0.4 mm) diam holes 5 cm apart on the upper side of the tube. The tube was plugged at one end and connected to the gas inlet tube at the other end.

### Nitrogen purging and artificial carbonation of brines

Aqueous, acidified brines in pilot tanks were artificially carbonated and the efficiencies of the three types of spargers for $CO_2$ removal by nitrogen purging were tested. Subsequently, for purging and carbonation of brines, Porex tube spargers were used with pilot tanks and fritted-glass, gas dispersion tubes with 1 gal jars.

Duplicate controlled fermentations in pilot tanks were continuously nitrogen purged; the cucumbers and brine analyses were compared with those of nonpurged natural fermentations. In another experiment of controlled fermentation, brines in duplicate pilot tanks and 1-gal jars were purged with $N_2$ for 8 days, carbonated with 100% $CO_2$ for the next 6 days, then purged with $N_2$ for 8 days. Another set of duplicates was treated similarly, but carbonated with 68% $CO_2$ in $N_2$. The cucumbers were then removed and evaluated.

### Brining procedures

Cucumbers were brined in the pilot tanks at a pack-out ratio of ca 60/40, w/v, cucumbers/brine (220-lb cucumbers filled to 44 gal, or 166L, with brine). Depth of the brined cucumbers was 229 cm (7.5 ft). One-gal jars (3.8L), fitted with 250 ml "expansion reservoirs" as described previously (Fleming et al., 1973), were brined at a pack-out ratio of 50/50 (4.2-lb cucumbers filled to 1 gal with brine). Pilot tanks and jars were incubated at 27–29°C. Natural fermentations in tanks were brined to equalize at 25° salometer NaCl according to Etchells and Hontz (1972). Controlled fermentations in tanks and jars were brined according to Etchells et al. (1973), with 20 or 25° salometer brine treatments. Briefly, the controlled fermentation procedure involves acidification of the cover brine, addition of a sodium acetate buffer, inoculation with *Lactobacillus plantarum*, and removal of $CO_2$ from the brine by $N_2$ purging. Low ozone ultraviolet (2537 Angstroms), germicidal lamps were placed 50 cm directly above the brine surface of pilot tanks to prevent growth of film yeasts and molds. Commercial fermentations were carried out at ambient temperatures (25–28°C) in 10,000 gal (37.8 kl), 8-ft deep, wooden tanks typical of those used by the industry.

For determination of the effects of brine depth on quality of brine stock in commercial tanks, cucumbers bagged in about 25-lb lots were tied at three locations along 2.5- × 5-cm, wooden boards. Three such "pickle trees" were nailed vertically to the inside of the tank prior to filling. The three locations represented the approximate centers of the top, middle and bottom sections of the tank. The bags were made from tubular plastic netting, 38-cm "lay flat," with 1.5-cm mesh (Bemis Co., Inc., St. Louis, MO). Ends of the netting were tied to form a bag.

*Table 1—Assignment of numerical values to adjectival ratings for determination of the bloater index of brined cucumbers*

| Adjectival rating for degree of damage[a] | Weighted damage values (WDV) for bloater types: Balloon | Lens | Honeycomb |
|---|---|---|---|
| S (slight) | 20 | 10 | 5 |
| SM | 30 | 20 | 15 |
| SA | 35 | 25 | 20 |
| MS | 40 | 30 | 25 |
| M (moderate) | 50 | 40 | 35 |
| MA | 60 | 50 | 45 |
| AS | 65 | 55 | 50 |
| AM | 70 | 60 | 55 |
| A (advanced) | 85 | 75 | 70 |
| AA | 100 | 90 | 85 |

[a] When two letters are shown, the first indicates the degree of bloating in the majority of the cucumbers.

### Evaluation of brine stock

Brine-stock cucumbers were cut longitudinally and evaluated for bloater damage. The damage was categorized as to type (balloon, lens, honeycomb) and degree (slight, moderate, advanced) according to the "Bloater Chart" of Etchells et al. (1974). Shoup et al. (1976) estimated % recovery of brined cucumbers using this "Bloater Chart." Heretofore, we have reported damage as percentage of the cucumbers affected by each type of bloater, with a parenthetic adjectival rating for the degree of damage (Etchells et al., 1975; Fleming et al., 1973, 1975). For facilitating statistical analyses, we used a "bloater index" calculated from the numerical percentage of cucumbers affected and the degree of damage for each bloater type. Weighted damage values (WDV) were assigned to adjectival ratings of 10 degrees of damage (Table 1). The index for balloon bloater damage, for example, was calculated as: Balloon index = % affected by balloon damage × WDV for balloon type/100. Indexes for lens and honeycomb bloating were calculated similarly, and the overall bloater index was the sum of the three indexes: Bloater index = balloon index + lens index + honeycomb index.

The bloater index approximates the percentage of the cucumber tissue in a sample of stock, by volume, that is unsuitable for pickle products, such as hamburger dill chips which must be free of serious physical defects.

Percentage of cure was estimated by visual inspection of brine-stock cucumbers cut longitudinally. Cure, from a visual standpoint, refers to a change in the flesh from white, opaque to translucent.

Firmness was measured with a USDA Fruit Pressure Tester according to Bell and Etchells (1961). Adjectival ratings for pressure tests on no. 3 (3.8–5.1-cm diam) brine-stock cucumbers are: 20 lb and above = very firm; 16–19 lb = firm; 11–15 lb = inferior; 5–10 lb = soft; 4 lb and below = mushy (Etchells and Hontz, 1973).

### Brine analyses

Brines were sampled in the laboratory with sterile, 12-ml, plastic syringes (20-gauge needles) through rubber serum stoppers in the sides of the pilot tanks or in caps of jars. Commercial brines were sampled at mid-depth with a harpoon and siphoning apparatus (Fleming et al., 1974a; Etchells and Jones, 1946). Titratable acidity (calculated as lactic acid), pH, NaCl, and reducing sugars were determined by methods described or cited earlier (Fleming et al., 1973). Dissolved $CO_2$ was determined by microdiffusion and entrapment in standardized NaOH according to Fleming et al. (1974b).

## RESULTS & DISCUSSION

### Comparison of spargers for $CO_2$ removal

Rates of $CO_2$ removal from brines by nitrogen purging with three types of spargers are given in Figure 2. The ceramic diffuser was most efficient in $CO_2$ removal down to 30 mg $CO_2$/100-ml brine. At concentrations lower than that, the Porex tube sparger was equally efficient. The drilled tube sparger required about 1.4 times as much purging time with nitrogen gas to reduce the dissolved $CO_2$ to 30 mg/100-ml brine.

The Porex tube sparger was used in brining experiments for nitrogen purging and for carbonation of brines because of its ease of fabrication, durability and relative efficiency. The ceramic diffuser was more fragile and required considerably greater pressure than the Porex tube to allow gas into the brine (21 vs 4 psi). This difference in pressure was accounted for in the calculation of flow meter settings that would maintain flow at 50 ml/min (Fig. 2).

### Controlled and natural fermentations of cucumbers in pilot tanks

In nonpurged, natural fermentations, expansion volume peaked 7 days after brining at about 9.5% of the original volume of the cucumbers (Fig. 3). Peak volume indicated that rate of bloater formation had maximized. $CO_2$ concentrations at three depths were also maximal on day 7, apparently exceeding saturation (Fig. 3). Thereafter, brine $CO_2$ decreased in the top regions of the tanks, but remained constant at about 112 mg/100-ml brine at the bottom of the tanks. The expansion volume dropped after 7 days when brine began to fill the bloated cucumbers. The brine eventually fell below the original level probably because it both evaporated and replaced gas that had been present in the fresh cucumbers.

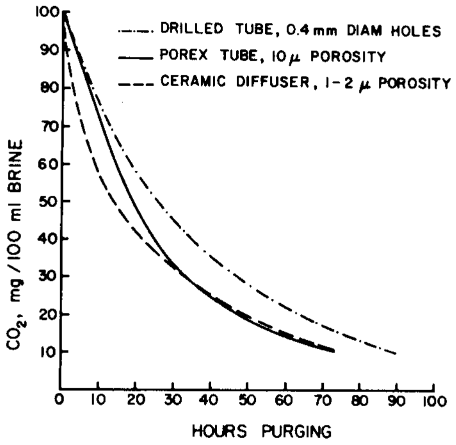

*Fig. 2—Comparison of spargers for purging $CO_2$ from brines. Brines, 25° salometer NaCl, 27°C, were adjusted to pH 4.0 with lactic acid and carbonated. The brines were then purged with nitrogen at a flow rate of 50 ml/min.*

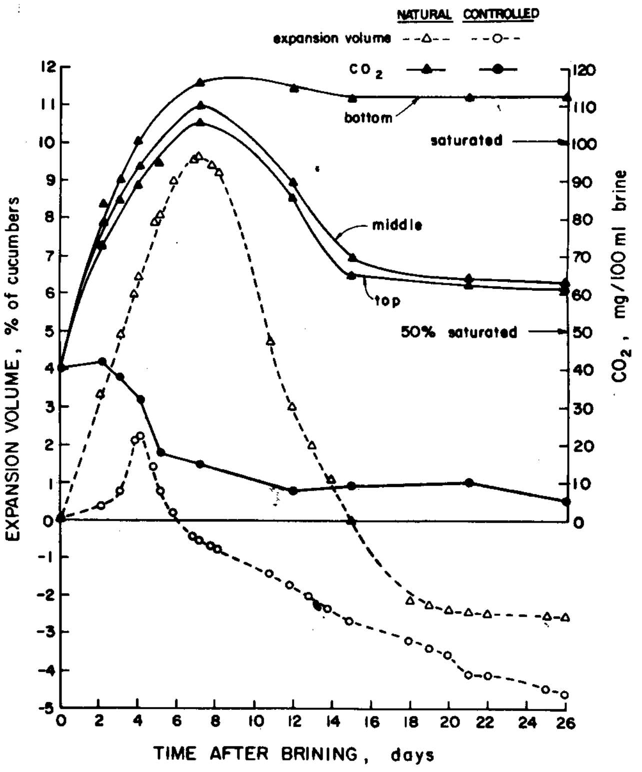

*Fig. 3—$CO_2$ and expansion volume changes during controlled and natural fermentations in pilot-scale tanks. See footnote a, Table 2, for details.*

Expansion volume in $N_2$-purged, controlled fermentations maximized at only 2% of the original volume of cucumbers after 4 days; brine then fell below the initial level (Fig. 3). The concentration of $CO_2$ in the brine was 42 mg/100-ml for the first 2 days after brining and decreased therafter.

Bloater damage was greater in natural than controlled fermentations, as expected (Table 2). In controlled fermentations, the bloater index was significantly greater for cucumbers in the top than in the middle and bottom sections of the tanks. In natural fermentations, bloater indexes were greater for the top and bottom than for the middle cucumbers.

The cured appearance of the controlled fermentation brine stock after 26 days' storage increased strikingly with brine depth (Table 2). The response was linear ($P \leqslant 0.01$, Table 3). Cure was not affected by depth in natural fermentations.

Pressure test values of brine stock in natural fermentations increased with brine depth, but did not vary significantly in controlled fermentations (Tables 2 and 3). Overall, brine stock from controlled fermentations was firmer than from natural fermentations.

### Artificial carbonation of controlled fermentation cucumbers

Carbonation of brines by $CO_2$ bubbled through the solutions caused bloater formation of cucumbers in the pilot tanks, as manifested by a prompt increase in expansion volume (Fig. 4). Removal of $CO_2$ by nitrogen purging resulted in an immediate drop in the brine level.

Total bloater index was significantly greater ($P \leqslant 0.01$) for cucumbers carbonated with 100% $CO_2$ than with a 68% $CO_2$

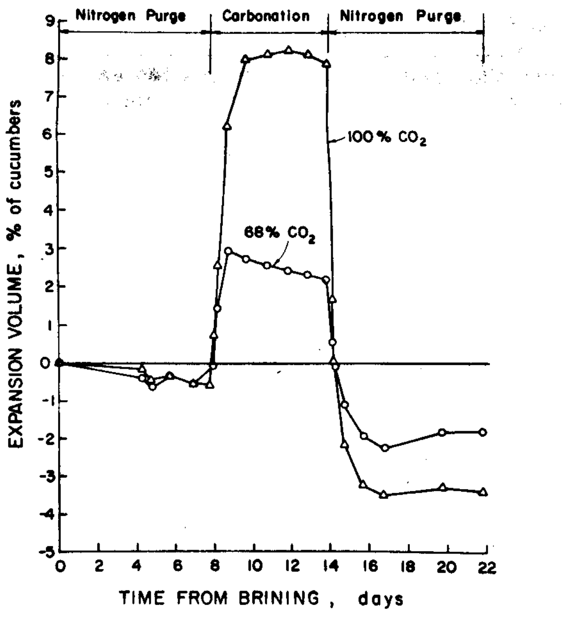

*Fig. 4—Expansion volume changes in controlled fermentations carbonated at two concentrations of $CO_2$. See footnote a, Table 4, for details.*

*Table 2—Effect of brine depth on cucumbers fermented in pilot tanks*[a]

| Fermentation type | Tank location: Section | Tank location: Mean depth (cm) | Bloater index: Balloon | Bloater index: Lens | Bloater index: Honeycomb | Bloater index: Total | Maximum brine $CO_2$[b] (mg/100 ml) | Cure (%) | Pressure test (lb) |
|---|---|---|---|---|---|---|---|---|---|
| Natural | Top | 38 | 19.6 | 3.6 | 16.9 | 40.1 | 106 (7) | 75 | 15.8 |
| | Middle | 114 | 8.0 | 2.0 | 7.3 | 17.3 | 110 (7) | 82 | 17.8 |
| | Bottom | 190 | 26.8 | 7.5 | 17.1 | 51.4 | 121 (20) | 82 | 18.6 |
| Controlled | Top | 38 | 5.4 | 0.0 | 5.9 | 11.3 | 42 (2) | 40 | 19.0 |
| | Middle | 114 | 0.0 | 0.8 | 3.1 | 3.9 | 42 (2) | 60 | 19.7 |
| | Bottom | 190 | 2.2 | 0.8 | 0.7 | 3.7 | 42 (2) | 94 | 19.4 |

[a] Size no. 3 cucumbers were brined in duplicate pilot tanks according to the 25° salometer brining treatment; incubation was at 29°C for 26 days. Only the controlled fermentations were purged of $CO_2$. The salt was 6.2%, w/v, at equalization. Values are averages of duplicate fermentations.
[b] Maximum $CO_2$ values are for individual fermentations. For average values of the duplicate fermentations, see Figure 3. Values in parentheses are the days after brining at which $CO_2$ was maximum.

(Tables 4 and 5). The overall percentages of cucumbers affected were about the same, but the degree of damage in those affected was much greater with 100% $CO_2$. These data illustrate the advantage of expressing damage as a bloater index, a value that encompasses percent affected as well as the degree of damage.

Bloater damage decreased linearly ($P \leqslant 0.01$) with brine depth at both concentrations of $CO_2$ (Tables 4 and 5). Greater hydrostatic pressures at deeper regions of the tanks apparently counteracted gas pressures inside the cucumbers so that bloater damage was less than in the upper regions. Bloater index as a function of brine depth is illustrated in Fig. 5. Volume recovery was greater in cucumbers from the lower regions of the tank (Table 4).

After the 22 days' storage, cucumbers appeared more cured from the lower than the upper regions of the tanks (Fig. 6), although the effect of depth was not as striking as noted earlier for controlled fermentations that were nitrogen purged (Table 2). Increasing hydrostatic pressure appeared to increase the degree of cure. The white, opaque appearance of uncured tissue has been attributed to entrapped gas (Etchells and Ohmer, 1941; Fellers and Pflug, 1968). Increased pressure probably speeded loss of this undissolved gas.

Bloater indexes for cucumbers brined in 1 gal jars were appreciably less than those for cucumbers in the top sections of the pilot tanks, at corresponding concentrations of $CO_2$ (Table 4). The jars were about as deep as the top section of the tanks.

We attribute the greater bloater damage in the top section of tanks than in jars to greater buoyancy pressure exerted on cucumbers in the top sections of pilot tanks. This pressure crushed the cucumbers, rendering them more susceptible to bloater damage. An estimate of bloater index (BI) due to the buoyancy pressure is the difference in bloater index for the top section of the tanks and for the jars at the same $CO_2$ concentration. Thus: with 68% $CO_2$ for carbonation, 32.4 (BI tank) - 10.9 (BI jar) = 21.5 BI due to buoyancy or 66% of the total damage; with 100% $CO_2$ for carbonation, 57.8 (BI tank) - 32.9 (BI jar) = 24.9 BI due to buoyancy or 43% of the total damage.

Pressure test values were less for cucumbers carbonated in pilot tanks with 100% $CO_2$ than with 68% $CO_2$ (Table 4). The greater bloater damage in 100% carbonated cucumbers may account for this difference, even though we tested cucumbers that appeared not to have bloater damage.

### Controlled and natural fermentations of cucumbers in commercial tanks

Nonpurged, duplicate natural fermentations in 1,000 bu

*Table 3—Analysis of variance for effects of brine depth on cucumbers in controlled and natural fermentations in pilot tanks*[a]

| Variable | Source of variation | df | Mean square: Fermentation: Controlled | Mean square: Fermentation: Natural |
|---|---|---|---|---|
| % Cure | Depth (linear) | 1 | 2916.00** | 56.25 |
| | Depth (dev from linear) | 1 | 65.33 | 18.75 |
| | Error | 3 | 10.67 | 75.00 |
| Pressure test | Depth (linear) | 1 | 2.50 | 78.40** |
| | Depth (dev from linear) | 1 | 2.70 | 4.80 |
| | Error | 57 | 13.21 | 8.88 |
| Bloater index (total) | Depth (linear) | 1 | 19.25* | 42.56 |
| | Depth (dev from linear) | 1 | 5.76 | 359.73* |
| | Type [B vs (L + H) ] | 1 | 1.69 | 328.82* |
| | Type (L vs H) | 1 | 21.87* | 265.08* |
| | Type X depth | 4 | 8.12 | 28.78 |
| | Error | 17 | 6.48 | 49.64 |

[a] See Table 2 for treatment totals and footnote a of Table 2 for details of the experiment.
* $P \leqslant 0.05$.
** $P \leqslant 0.01$.

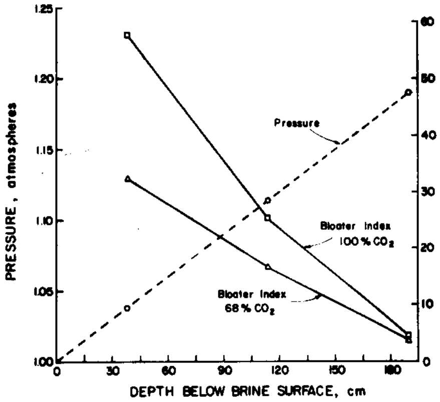

*Fig. 5—Bloater index and hydrostatic pressure as functions of brine depth in controlled fermentations that were carbonated. See footnote a, Table 4, for details and Figure 4 for the corresponding expansion volume changes.*

*Table 4—Effect of brine depth on cucumbers held under specified concentrations of dissolved $CO_2$ during controlled fermentation*[a]

| Carbonation gas, % $CO_2$ | Tank location | Bloater index[b] |  |  |  | Dissolved $CO_2$ [c] (mg/100 ml) | Cucumber volume recovery[d] (%) | Cure (%) | Pressure test (lb) |
|---|---|---|---|---|---|---|---|---|---|
|  |  | Balloon | Lens | Honeycomb | Total |  |  |  |  |
| Pilot tanks |  |  |  |  |  |  |  |  |  |
| 68 | Top | 15.6 (26 MA) | 0.8 (2 M) | 16.0 (71 MS) | 32.4 (99) | 73 | 92.0 | 68 | 18.0 |
|  | Middle | 9.8 (22 MS) | 0.8 (2 M) | 2.0 (39 S) | 12.6 (68) | 73 | 99.4 | 70 | 18.8 |
|  | Bottom | 3.5 (7 M) | 0.2 (2 S) | 0.1 (2 S) | 3.8 (11) | 75 | 100.0 | 84 | 18.4 |
| 100 | Top | 49.7 (71 AM) | 4.0 (7 AM) | 4.1 (18 MS) | 57.8 (96) | 107 | 81.8 | 72 | 16.6 |
|  | Middle | 21.8 (38 MA) | 0.0 (0) | 3.4 (35 S) | 25.2 (73) | 109 | 90.0 | 75 | 17.7 |
|  | Bottom | 4.0 (10 MS) | 0.4 (1 M) | 0.4 (3 SM) | 4.8 (14) | 112 | 100.0 | 92 | 17.9 |
| 1 gal jars |  |  |  |  |  |  |  |  |  |
| 68 |  | 6.5 | 1.9 | 2.5 | 10.9 | 74 |  | 68 | 18.4 |
| 100 |  | 23.8 | 0.4 | 8.7 | 32.9 | 109 |  | 79 | 18.8 |

[a] Size no. 3 cucumbers were brined in duplicate pilot tanks and 1 gal jars according to the 20° salometer brining treatment; incubation was at 27°C for 22 days. The brines were nitrogen purged for 8 days, carbonated with either $CO_2$ or 68% $CO_2$ in nitrogen from days 8 to 14, then nitrogen purged to remove the dissolved $CO_2$ as illustrated in Figure 4.

[b] Numerical values in parentheses are percentages of cucumbers affected by bloater damage. Letters are adjectival ratings for degree of damage as explained in Table 1.

[c] Represents the highest $CO_2$ values obtained over a 2-day period during carbonation (days 11 and 12 after brining).

[d] Volume recovery, %, of brine-stock cucumbers was: the volume of 50 cucumbers ÷ the volume of 50 unbloated cucumbers X 100. The cucumbers were cut longitudinally before volume measurement, so that brine could enter the bloated areas. The volume of the cut cucumbers was determined by brine displacement in a calibrated container.

commercial tanks showed that bloater damage increased with depth of brining (Table 6). This relationship existed for three sizes of cucumbers, and was essentially linear ($P \leqslant 0.05$, Table 7). The concentration of $CO_2$ throughout the tanks showed that it exceeded saturation about 1 wk after the start of brining. Brines were effervescent, and $CO_2$ losses during siphoning and sampling made readings questionable. The two natural fermentations differed significantly in bloater damage ($P \leqslant 0.01$, Table 7), supporting our previous observations on variations among natural fermentations.

Bloater damage of comparable sizes of cucumbers was much less in purged, controlled fermentations than in nonpurged, natural fermentations (Table 6). The $CO_2$ concentration was maintained below 40 mg/100-ml brine in controlled fermentations. Damage was significantly greater ($P \leqslant 0.05$) in the top sections of these tanks (Table 6).

*Table 5—Analysis of variance for the effects of brine depth and $CO_2$ concentration on bloater damage in controlled fermentations of brined cucumbers*[a]

| Source of variation | df | Mean square |  |
|---|---|---|---|
|  |  | % Affected | Bloater index |
| Bloater type | 2 | 2741.78** | 899.31** |
| $CO_2$ conc | 1 | 11.11 | 169.43** |
| Type X $CO_2$ conc | 2 | 1200.44** | 295.51** |
| Depth (linear) | 1 | 4816.67** | 1108.41** |
| Depth (dev from linear) | 1 | 150.22 | 30.55 |
| Type X depth (linear) | 2 | 964.66** | 380.97** |
| Type X depth (dev from linear) | 2 | 176.22 | 2.02 |
| $CO_2$ conc X depth (linear) | 1 | 6.00 | 98.82* |
| $CO_2$ conc X depth (dev from linear) | 1 | 22.00 | .09 |
| Type X $CO_2$ conc X depth (linear) | 2 | 1176.00** | 272.60** |
| Type X $CO_2$ conc X depth (dev from linear) | 2 | 176.86 | 28.56 |
| Pooled error | 18 | 63.55 | 20.58 |

[a] Combined analysis made by orthogonal comparisons of replicate totals. See Table 4 for treatment means and further details.

* $P \leqslant 0.05$.

** $P \leqslant 0.01$.

*Table 6 — Effect of brine depth on cucumbers fermented in commercial brining tanks*[a]

| Cucumber size | Tank location | Bloater index |  |  |  | Cure (%) | Pressure test (lb) | Soft center (%) |
|---|---|---|---|---|---|---|---|---|
|  |  | Balloon | Lens | Honeycomb | Total |  |  |  |
| Natural fermentation |  |  |  |  |  |  |  |  |
| 2 | Top | 12.0 | 1.6 | 1.0 | 14.6 | 88 |  | 0 |
|  | Middle | 16.4 | 1.9 | 0.5 | 18.8 | 86 |  | 0 |
|  | Bottom | 18.2 | 8.6 | 0.8 | 27.6 | 76 |  | 0 |
| 3 | Top | 37.8 | 4.3 | 1.6 | 43.7 | 100 | 15.8 | 1 |
|  | Middle | 45.2 | 5.3 | 0.2 | 50.7 | 98 | 16.1 | 4 |
|  | Bottom | 43.8 | 6.6 | 1.0 | 51.4 | 71 | 16.7 | 0 |
| 4 | Top | 45.8 | 0.3 | 0.0 | 46.1 | 100 |  | 28 |
|  | Middle | 51.5 | 0.1 | 0.0 | 51.6 | 99 |  | 30 |
|  | Bottom | 63.2 | 0.2 | 1.9 | 65.3 | 88 |  | 27 |
| Controlled fermentation |  |  |  |  |  |  |  |  |
| 3 | Top | 6.9 | 6.0 | 2.3 | 15.2 | 79 | 15.6 | 0 |
|  | Middle | 0.3 | 1.2 | 0.0 | 1.5 | 100 | 15.4 | 0 |
|  | Bottom | 0.0 | 0.3 | 0.0 | 0.3 | 100 | 17.0 | 7 |
| 4 | Top | 9.2 | 0.0 | 0.0 | 9.2 | 82 | 19.0 | 3 |
|  | Middle | 1.9 | 0.0 | 0.0 | 1.9 | 100 | 19.9 | 11 |
|  | Bottom | 5.2 | 0.0 | 0.0 | 5.2 | 100 | 19.2 | 1 |

[a] Fermentations were at 25–28°C and 25° salometer. Natural fermentations were in duplicate tanks containing bagged samples of 3 sizes of cucumbers at 3 depths in 3 separate locations. Controlled fermentations consisted of 1 tank each of size no. 3 and no. 4 cucumbers.

Firmness of the stock did not vary significantly with brine depth in natural or controlled fermentations. Cured appearance was greatest for stock in the top regions of natural fermentations and in the lower regions of controlled fermentations. Soft centers were especially prominent (nearly 30%) in size no. 4 cucumbers in natural fermentations. This defect, in addition to bloater damage, made these cucumbers practically useless for hamburger dill slices. Brine-stock cucumbers with soft centers are a source of economic loss to brining operations, being poor to unacceptable even for relish. Soft centers were not prevalent in controlled fermentations, perhaps due, in part, to differences in cucumbers since the tanks were brined at different times.

### How brine depth affected bloater damage

Brine depth in uncovered tanks affected bloater damage of brined cucumbers by three primary means:

(1) Depth influenced the build-up of $CO_2$ in nonpurged brines. $CO_2$ concentration in the brine varied directly with depth (Table 2, and Etchells et al., 1975). The extent of bloater damage was related directly to $CO_2$ concentration (Table 4 herein, and Fleming et al., 1973, 1975).

(2) At constant $CO_2$ concentration, increased hydrostatic pressure at greater depths reduced bloater damage (Table 4).

(3) Buoyancy pressure on cucumbers in the upper regions of tanks increased with depth of the brine and resulted in increased bloater damage to the cucumbers (Table 4 and related discussion).

Assessment of the effect of brine depth on bloater damage requires that all three of the above factors be considered. When $CO_2$ was uniform throughout the brine of controlled fermentations, effects of $CO_2$ concentration and hydrostatic pressure, as indicated above, were clearly evident (Table 4, Fig. 5). Effects of buoyancy pressure on damage were estimated indirectly.

Differences in the effects of brine depth on damage in nonpurged, natural fermentations in commercial (Table 6) and pilot (Table 2) tanks show that the causes of damage when $CO_2$ is not uniform are complex and not readily delineated.

The role of buoyancy in bloater damage is complex because of changes that occur during early stages of brining. Tanks are headed down so that cucumbers are prevented from rising above the brine surface. The buoyancy force exerted against the cucumbers is greatest at the top of the tank. Also, higher pack-out ratios, cucumbers/brine, result in greater total buoyancy. The buoyancy of fresh cucumbers in brine is increased when they become bloated. Fresh cucumbers vary in density and have been separated on that basis; susceptibility to bloater damage has been shown to decrease with increasing density of cucumbers (Marshall et al., 1973). The high buoyancy of low density cucumbers may be an important factor influencing physical damage of cucumbers during brining. Carpel separation and rupture of the flesh could then render the cucumbers more susceptible to bloater formation. The cucumbers gradually lose their buoyancy as brine penetrates the flesh.

Brining at high initial salt strengths would make cucumbers more buoyant and could influence the extent of damage. Thus, lower initial brine strengths, and lower rates of salt addition during storage would minimize the damage caused by buoyancy pressure. Certain minimum brine strengths are necessary, however, to prevent softening of the cucumbers. These considerations further emphasize the importance of careful attention to salting of cucumbers.

### Consideration of depth in design of new brining tanks

Removal of $CO_2$ from brines would allow the brining of cucumbers in tanks deeper than those presently used. $CO_2$ removal would reduce bloater damage, and reduce breakage of the tanks and head boards due to excessive pressures resulting from bloater formation. At increasing depths, resistance to bloater damage would increase and cure would be hastened because of greater hydrostatic pressure. On the other hand, physical damage to cucumbers near the top of the tank caused by buoyancy pressure would increase as the depth of the brined cucumber mass is increased. In our tests of purged, controlled fermentations, damage to cucumbers near the top was not severe when the total brine depth was 229 cm (7.5 ft). Greater depths may cause more severe damage in the upper regions of the tank; therefore, a practical limit on depth should be considered. This limit probably will be influenced by the size of the cucumbers. We have observed that large cucumbers are damaged more easily than small cucumbers in regard to carpel separation and rupture of the seed area. If deeper tanks are used, it may be desirable to partition them with horizontal supports held in place at various depths to distribute the buoyancy pressure.

*Table 7—Analysis of variance for effects of brine depth in commercial fermentations*[a]

| | Controlled fermentation | | Natural fermentation | |
|---|---|---|---|---|
| Source of variation | df | Mean square | df | Mean square |
| Tank | | | 1 | 710.64** |
| Depth (linear) | 1 | 89.61* | 1 | 545.41* |
| Depth (dev from linear) | 1 | 44.85 | 1 | 3.68 |
| Size | 1 | 0.07 | 2 | 1,985.61** |
| Depth X size | 2 | 15.09 | 4 | 24.69 |
| Error | 36 | 15.85 | | |
| Error A[b] | | | 8 | 68.48 |

[a] See Table 6 for treatment means and footnote a of Table 6 for details of the experiment.

[b] Error A = pooled mean square for the interactions: tank X depth, tank X size, tank X depth X size.

* $P < 0.05$.

** $P < 0.01$.

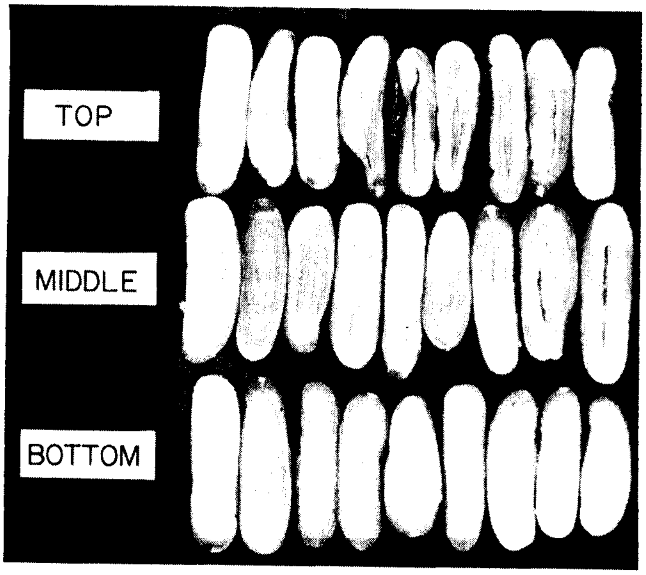

*Fig. 6—Brine-stock cucumbers showing effects of being brined at three depths. The cucumbers were brined and carbonated with 100% $CO_2$ as described in footnote a, Table 4.*