BRINING PROPERTIES OF CUCUMBERS EXPOSED TO PURE OXYGEN BEFORE BRINING

H. P. FLEMING, D. M. PHARR, and R. L. THOMPSON

ABSTRACT

Replacement of the internal gas atmosphere of pickling cucumbers with O_2 (O_2-exchanged) greatly altered their brining properties. Oxygen-exchanged cucumbers absorbed brine rapidly, apparently as a result of reduced pressure inside the cucumbers due to respiratory conversion of O_2 to CO_2. The brine uptake reached a maximum and approximated the gas volume reported for fresh cucumbers (4–5%) within 24 hr. Upon brining, the O_2-exchanged cucumbers acquired a translucent internal appearance of fully-cured, brine-stock cucumbers within a few days, as compared to several months for untreated brine stock. The O_2-exchanged cucumbers were less susceptible to bloater damage than control cucumbers during brine fermentation. The density of O_2-exchanged cucumbers was significantly greater than that of control cucumbers within a day after brining, due to the greater brine absorption. No important effects of O_2 treatment were noted regarding rate and extent of fermentation.

INTRODUCTION

BLOATER DAMAGE in brined cucumbers is associated with a build-up of CO_2 in the brine surrounding the cucumbers (Fleming et al., 1973a). The CO_2 may originate from microbial activity in the brine or from the cucumber tissue (Fleming et al., 1973b). Etchells et al. (1968) proposed that bloater formation occurs when the brine becomes *supersaturated* with CO_2. However, Fleming et al. (1978) found that bloater formation can occur at *subsaturation* levels of CO_2. Fleming and Pharr (1980) hypothesized that bloater formation occurs because of differences in rate of transfer of CO_2 and N_2 in the brined cucumbers. This difference in transfer rate was suggested to be related to liquid clogging of the intercellular air space in the outer layer of mesocarp tissue, with the liquid-clogged tissue functioning as a differentially permeable barrier to CO_2 and N_2. They proposed that CO_2 diffuses into the cucumber from the surrounding brine faster than N_2 diffuses out, resulting in a net increase in total pressure inside the cucumber, with resultant bloater formation.

Replacement of the internal gas of fresh cucumbers with CO_2 or O_2 prior to brining resulted in reduced susceptibility of the cucumbers to bloater damage and served as a partial basis for the above hypothesis (Fleming and Pharr, 1980). The O_2-exchanged cucumbers absorbed brine rapidly, and the cucumbers acquired a cured appearance within a day or so after brining; CO_2-exchanged cucumbers did not consume brine and acquire the appearance of cure as rapidly.

The purpose of this study was to learn the rate of O_2 exchange in fresh cucumbers, the rate and extent of brine uptake in O_2-exchanged cucumbers, and the brining properties (rate of fermentation, bloater formation, cure, firmness) of O_2-exchanged as compared to unexchanged cucumbers during brine storage.

Authors Fleming and Thompson are with the USDA Food Fermentation Laboratory, SEA-AR, Southern Region, and North Carolina Agricultural Research Service, Dept. of Food Science, North Carolina State Univ., Raleigh, NC 27650. Author Pharr is with the Dept. of Horticultural Science, North Carolina State Univ., Raleigh, NC 27650.

MATERIALS & METHODS

Cucumbers

Pickling cucumbers of size nos. 1, 2, 3, and 4 (1.9–2.7 cm, 2.7–3.8 cm, 3.8–5.1 cm, and 5.1–5.8 cm diam, respectively) were obtained from a nearby pickle company. Only cucumbers free of obvious physical damage and disease were used. Brined cucumbers were evaluated for bloater damage according to Etchells et al. (1974), and bloater indexes were calculated according to Fleming et al. (1977). Firmness of the brined cucumbers was determined with a USDA Fruit Pressure Tester, using a 5/16 inch diam plunger, according to Bell and Etchells (1961). Appearance of cure in brined cucumbers was estimated as the percentage of the surface area of longitudinally cut cucumbers which had a translucent appearance. Uncured flesh was white and opaque. Also estimated from examination of the longitudinally cut cucumbers was the percentage of the fruit with soft centers, i.e., soft and/or liquified seed area.

Gas exchange of cucumbers prior to brining

Cucumbers (1.9 kg) were packed into 3.8-liter (1-gal) glass jars. Each jar was fitted with an expansion reservoir and a gas inlet tube, as described previously (Fleming and Pharr, 1980). Before addition of the brine, O_2 was metered into the jars continuously or intermittently, as designated in individual experiments.

Brining

After gas exchange, brine was added through the reservoir and into the jar, while O_2 flow was continued in order to exclude air from the jar. Brines used for fermentation contained 10.6% (w/v) NaCl and 0.32% (v/v) glacial acetic acid. Sodium acetate (3 H_2O), 0.5% (w/v) at equalization, was added 24 hr after brining and just prior to inoculation. Brines were inoculated with *Lactobacillus plantarum* WSO (ca. 10^9 cells/3.8 liter brined cucumbers). This is the general procedure described in the controlled fermentation process of Etchells et al. (1973), except that chlorine was not added to sanitize the cucumbers.

Brines that were not intended for fermentation contained 10.6% NaCl, 0.32% acetic acid, and 0.2% sodium benzoate.

Brine uptake

Brine level in the expansion reservoir of O_2-exchanged cucumbers receded soon after addition of the brine. The drop in brine level was monitored in the graduated expansion reservoir. Brine drop was calculated as a percentage of the volume of the cucumbers.

Expansion volume

Expansion volume of the brined cucumbers was determined from the rise in the brine level in the reservoir (Fleming et al., 1973a) and was expressed as a percentage of the volume of the cucumbers in the jar.

Brine analyses

Brines were sampled with sterile, 10-ml plastic syringes through a rubber serum stopper placed in the cap of each jar. Titratable acidity (calculated as lactic acid), pH, NaCl, and reducing sugars were determined by methods described or cited earlier (Fleming et al., 1973a). Dissolved CO_2 was determined by microdiffusion and entrapment in standardized NaOH according to Fleming et al. (1974).

Density of brined cucumbers

Cucumbers (five per determination) were removed from brines, blotted dry, and then weighed in a 2-liter graduated cylinder. The weight of water (25°C) needed to bring the volume to 2 liters in the cylinder was determined. The cucumbers were wedged in the cylinder so that they could not float when covered with water. The volume of cucumbers was determined as the difference in the volume of water added (assuming a density of one for water at 25°C) and the 2-liter total volume of the cylinder. Cucumber density was calculated as the cucumber mass divided by the cucumber volume at 25°C.

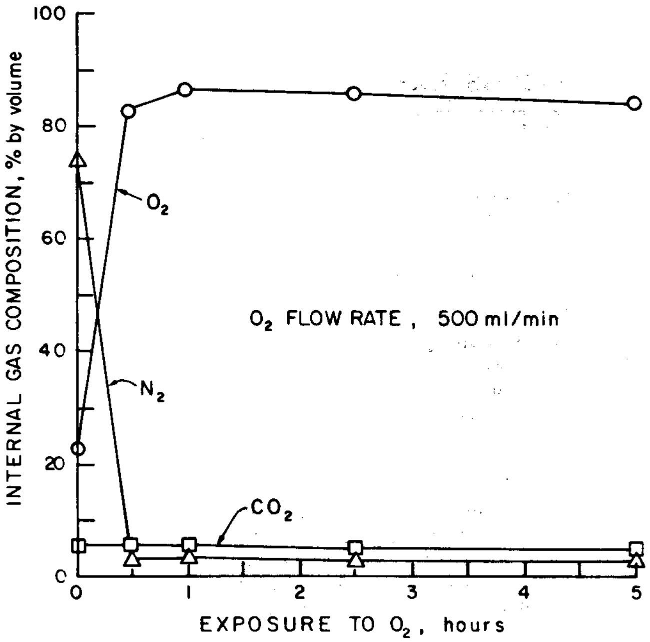

Fig. 1—Internal gas composition of fresh cucumbers exposed to O_2 in 1-gal jars.

Gas extraction and analysis

Gases were extracted from cucumbers and analyzed as described previously (Fleming and Pharr, 1980).

RESULTS

Oxygen exchange in fresh cucumbers

When fresh cucumbers were exposed to pure O_2 at a flow rate of 500 ml/min/gal of cucumbers, the internal gas composition of the fruit reached nearly 90% O_2 in 1 hr (Fig. 1). The exchange was about 95% complete in 0.5 hr, and this exchange rate is similar to the rate of CO_2 exchange in fresh cucumbers (Fleming and Pharr, 1980).

Brine uptake of O_2-exchanged cucumbers

When brine was added to O_2-exchanged cucumbers, the brine level began to recede within a few minutes and reached a plateau within ca. 20 hr for all four sizes of cucumbers tested (Fig. 2). The brine level of unexchanged cucumbers receded only slightly, and then rose slightly during the 20-hr brine storage period.

Cucumbers were exchanged continuously (Fig. 3A) or intermittently (Fig. 3B) with O_2. The maximum brine drop for the no. 3 size cucumbers was about 4.5% of the volume of the cucumbers by each method of exchange. Continuous O_2 at 100 ml/min/gal for ca. 1 hr or two intermittent introductions of O_2 at 300 ml/min/gal for 6 min. at 15 min intervals was sufficient to produce the maximum brine drop.

Fermentation and bloater damage of O_2-exchanged cucumbers

Cucumbers exposed to four intermittent exchanges of O_2 bloated only slightly, whereas unexchanged cucumbers had significant bloater damage, as evidenced by bloater index and brine expansion volume (Table 1; Fig. 4). Two O_2 exchanges resulted in intermediate bloater damage. The rate and extent of acid production was not altered appreciably by the O_2 treatments ($P > 0.05$). CO_2 levels in the fermentation brine (Table 1) after 7 days were not significantly affected by the O_2 treatments ($P > 0.05$).

Physical properties of brined cucumbers

There was a direct relationship between the time of exposure of fresh cucumbers to continuous O_2 flow prior to brining and the appearance of cure of the internal flesh 24 hr after brine addition (Fig. 5). Also, maximum brine uptake and the appearance of cure in the cucumbers were directly related, as may be seen by a comparison of Figures

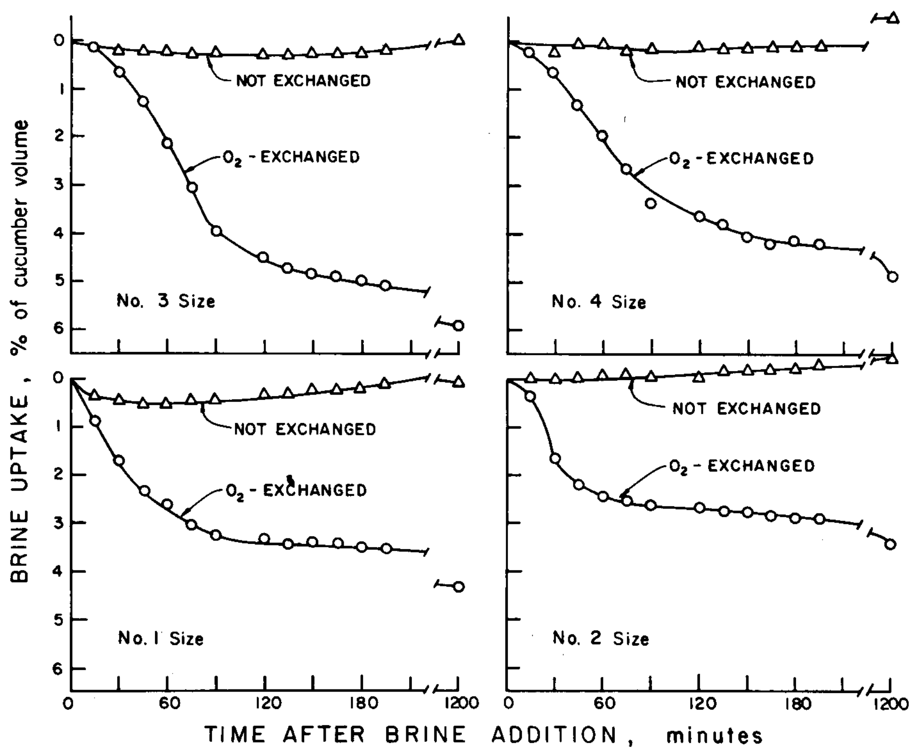

Fig. 2—Brine uptake by O_2-exchanged and untreated cucumbers of four sizes. The O_2-exchanged cucumbers had been exposed to O_2 at 50 ml/min/gal cucumbers for 1 hr before brining.

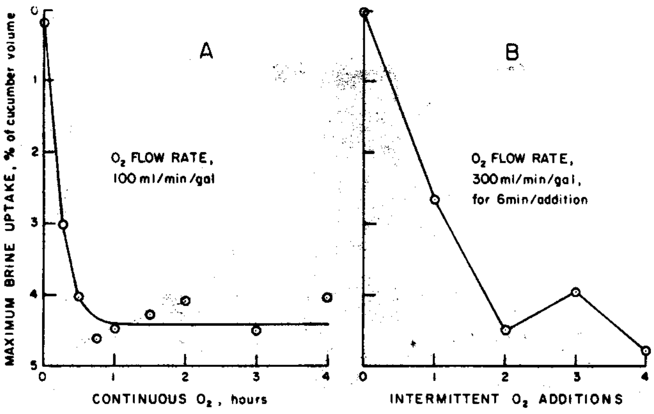

Fig. 3—Effect of continuous or intermittent additions of O_2 to no. 3 size cucumbers prior to brining on subsequent brine uptake by the cucumbers. For intermittent additions, there was a 15-min interval between additions. See Fig. 4 and 5 for related information.

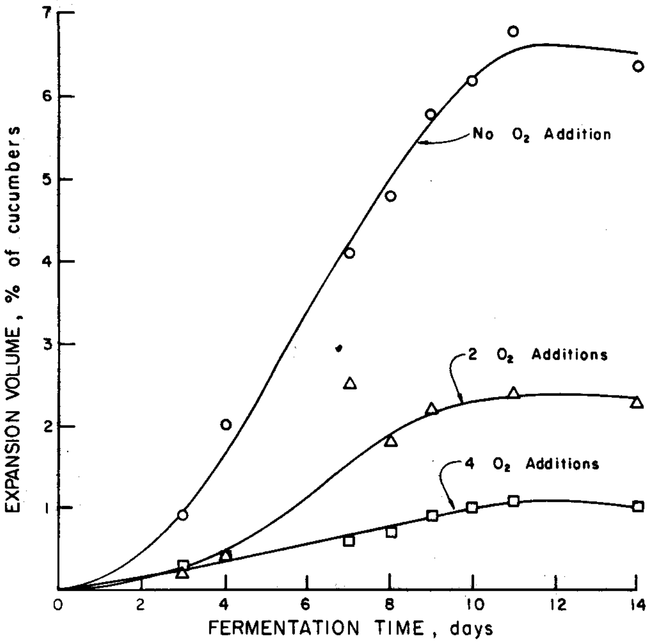

Fig. 4—Effect of O_2 additions to freah cucumbers upon subsequent bloater damage of the brined, fermented cucumbers. Expansion volume of the brine was used as an indicator of bloater formation. See Fig. 3 for explanation of intermittent O_2 additions.

Table 1—Effect of O_2 exchange in fresh cucumbers on bloater damage and fermentation of the brined cucumbers[a]

			Brine analyses[c]		
Intermittent O_2 exposures[b]	Bloater index	Expansion volume (%)	pH	Acid (%)	CO_2 (mg/100 ml brine)
0	20.2	6.8	3.55	0.74	66.4
2	9.5	2.4	3.57	0.76	75.3
4	1.5	1.1	3.64	0.70	74.4
LSD 0.05	12.3	3.8	0.18	0.11	13.0

[a] See Figures 3 and 4 and Table 2 for related information.
[b] O_2 at 500 ml/min for 6 min per exposure. O_2 added two or four times, intermittently, with 15-min intervals between additions.
[c] Determined after fermentation for 7 days.

3 and 5. Likewise, O_2-exchanged cucumbers, obtained by intermittent exposures of fresh cucumbers to O_2, acquired an almost fully-cured appearance after being in brine for only 4 days (Table 2). The white, opaque appearance, typical of fresh cucumbers, was absent. The cucumbers were translucent and light olive green inside, typical of fully-cured, brine-stock pickles. Cucumbers that were not O_2 exchanged did not acquire a fully-cured appearance even after 90 days of brine storage. Fermented and unfermented cucumbers exhibited the above behavior (Table 2).

Firmness of the brined cucumbers was not significantly affected by the O_2-exchange treatments due to fermentation, number of O_2 exchanges, and storage time ($P > 0.05$ by ANOVA). A preliminary experiment suggested that the occurrence of soft centers may be more prominent in O_2-exchanged cucumbers which were subsequently brined. A more extensive experiment (Table 2) did not support that suggestion.

Density of brined cucumbers

Early brining tests showed that control cucumbers were more buoyant than O_2-exchanged cucumbers, after they had been in brine for a few days. The control cucumbers were pressed tightly against the jar lid; whereas, O_2-exchanged cucumbers floated freely or settled to the bottom of the container. Further experimentation confirmed that O_2-exchanged cucumbers were more dense than unexchanged cucumbers ($P < 0.01$) within the first 24 hr after brining (Fig. 6). Water uptake by the O_2-exchanged cucumbers accounted for an increase of 0.038 g/ml in cucumber density, as shown by density intercepts (0% NaCl in the cover brine) in Figure 6. The density of the cucumbers increased as the salt concentration in the cover brine was increased, the rate of increase being greater for O_2-exchanged than unexchanged cucumbers ($P < 0.01$). Although liquid uptake of the cucumbers maximized within the 24-hr period, NaCl within the brine and cucumbers did not reach equilibrium for several days. Therefore, cucumber densities continued to increase beyond those shown in Figure 6, until salt equilibrium was attained.

DISCUSSION

OXYGEN REPLACEMENT of the gases within fresh pickling cucumbers apparently lowered the gas pressure inside the cucumbers when they were placed in brine, and, thereby, caused liquid to be taken into the tissue. We think that O_2 was quickly converted to CO_2 by respiratory activity within the cucumbers when the fruit were brined. As O_2 was metabolized to CO_2, the resulting gas pressure due to CO_2 was less than that formerly due to O_2 because of the greater solubility of CO_2 (CO_2 is 80 times more soluble than O_2 in water at 27°C, Hodgman et al., 1955). Carbon dioxide dissolves in tissue fluids much more than O_2 does. The lowered gas pressure inside the cucumbers caused brine to move into the cucumbers, thus accounting for the brine drop. Forward (1959) noted that the concentration of dissolved CO_2 parallels the concentration of CO_2 in the gaseous phase of fruit, and concluded that CO_2 must equilibrate rapidly between liquid and gas phases inside the fruit. Her reasoning is consistent with out hypothesis that pressure drops inside the O_2-exchanged and brined cucumbers.

We attributed the rapid appearance of cure in the O_2-exchanged cucumbers to the rapid uptake of brine and its replacement of gas inside the fruit. The white opaqueness of fresh cucumbers has been attributed to the presence of gas within the tissue (Veldhuis and Etchells, 1939). Brined cucumbers normally acquire a cured appearance gradually over a period of months. In unexchanged, brined cucumbers, N_2 is the primary internal gas (Fleming and Pharr, 1980), and its displacement from the interior of the fruit

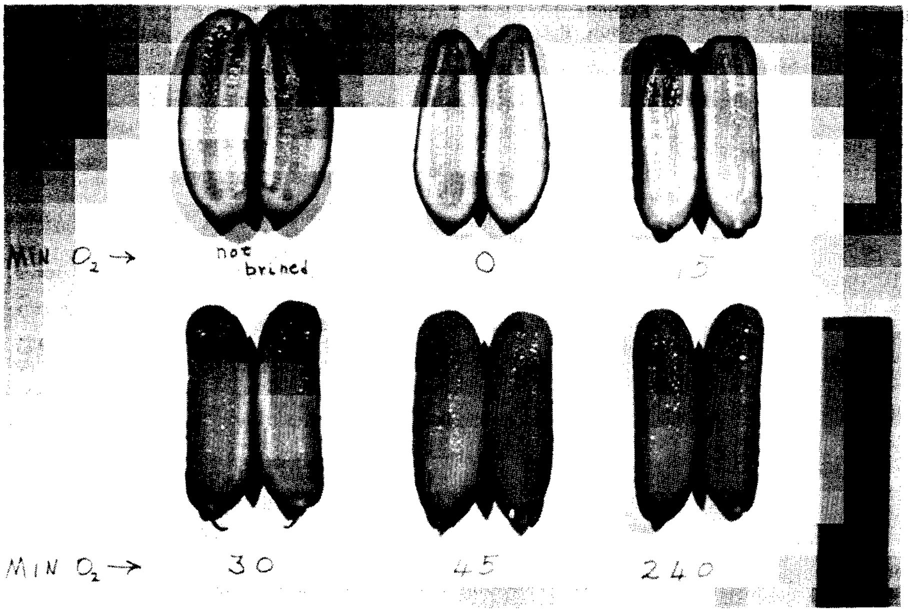

Fig. 5—Effect of exposure time of fresh cucumbers to a continuous O_2 flow on visual cure of the internal flesh 24 hr after addition of brine. Note the raw (white, opaque) appearance in the "not brined" cucumbers as compared to the progressive increase in cured appearance with increasing exposure time to O_2. See Fig. 3 for related information.

apparently is slow, at least partly because of its low solubility.

The reduced susceptibility of O_2-exchanged cucumbers to bloater damage was probably due to the removal of N_2 from the interior of the fruit, as reasoned earlier (Fleming and Pharr, 1980), and to brine filling the intercellular air spaces. In unexchanged cucumbers, N_2, because it is less water soluble than CO_2, diffused out of the brined fruit slower than CO_2 diffused in from the fermenting brine; hence, the internal gas pressure of the fruit, due to the combined partial pressures of N_2 and CO_2, increased. Brine uptake by O_2-exchanged cucumbers eliminated intercellular gas spaces that probably serve as nuclei for bloater formation. Marshall et al. (1973) reported that balloon bloater formation in brined cucumbers was inversely related to density of the green cucumbers. Low density cucumbers apparently have a greater volume of intercellular air space than high density cucumbers, and this difference may account for lower bloating susceptibility of high density fruit.

Alteration in the brining properties of O_2-exchanged cucumbers may offer several practical advantages. Greater tolerance of O_2-exchanged cucumbers to brine CO_2 would lower purging costs, since less N_2 would be required to maintain CO_2 at levels higher than those currently sug-

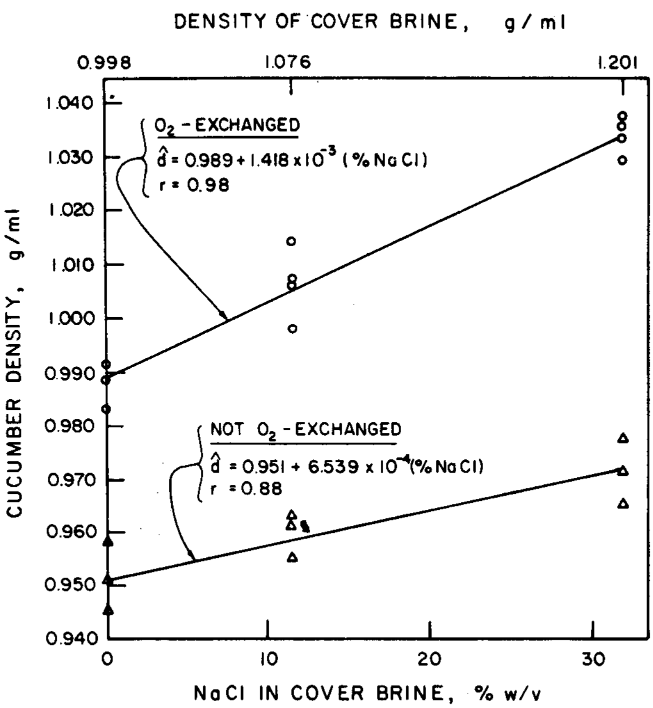

Fig. 6—Effect of O_2 exchange in cucumbers upon density of the brined cucumbers. Densities (d) were determined after the cucumbers had been in brine for 24 hr at 25°C.

Table 2—Effect of O_2 exchange in fresh cucumbers on physical properties of the brined cucumbers[a]

No. of intermittent O_2 exposures[b]	Days of brine storage	Soft centers, (%)	Pressure test (lb)	Cure, (%)
Fermented				
0	4	4	16.7	2
	14	0	18.0	30
	90	15	18.2	80
2	4	0	16.8	92
	14	4	17.9	96
	90	4	17.9	100
4	4	4	17.4	100
	14	4	17.9	97
	90	19	18.3	100
Not fermented				
0	4	0	17.2	5
	14	12	16.4	12
	90	8	17.6	65
2	4	8	15.3	98
	14	27	17.8	100
	90	23	16.6	100
4	4	0	17.6	100
	14	12	18.6	100
	90	23	16.6	100

[a] Values are averages from duplicate 1-gal jars, each containing 13 no. 3 size cucumbers.
[b] See footnote "a" for Table 1 for explanation of intermittent exposures.

gested. Originally, it was recommended that brine CO_2 be maintained below 20 mg/100 ml brine (Etchells et al., 1973). More recently, concentrations of 30–60 mg CO_2/100 ml brine have been suggested, depending on the brine temperature (Fleming, 1979).

The rapid appearance of cure in O_2-exchanged cucumbers may be of importance in certain applications. For example, some picklers state that their customers insist upon hamburger dill chips that appear fully cured. The controlled fermentation of cucumbers (Etchells et al., 1973) results in fully fermented cucumbers within about 10 days. The cucumbers have no residual sugar and are, therefore, stable to secondary fermentation; nevertheless, certain customers apparently object to them because they have a raw, uncured appearance.

Nitrogen-purged cucumbers acquire the cured appearance more slowly than unpurged cucumbers (Fleming, 1979). In contrast, air-purged cucumbers acquire a cured appearance faster than unpurged cucumbers. Reasons for the rapid cure in air-purged, brined cucumbers are unknown.

Cucumbers are buoyant when first brined, due largely to the gas trapped inside the fruit and to the high salt level of the cover brine. Marshall (1975) reported that the specific gravities of fresh cucumbers depended on cultivar and ranged from 0.958–0.982. Fresh cucumbers may be placed in brines of up to 40° salometer (density, 1.076) commercially. Buoyancy causes the fruit to be forced upward against the headboards, which are inserted into the brining tank to keep the cucumbers submerged. This buoyancy pressure can cause physical damage to the cucumbers, particularly those in the upper levels of the tank. It is possible to increase the density and thereby reduce the buoyancy of cucumbers rapidly by first treating them with O_2. The uptake of brine increases the desnity of the cucumbers and, thereby, reduces buoyancy of the fruit during early stages of brine storage.

REFERENCES

Bell, T.A. and Etchells, J.L. 1961. Influence of salt (NaCl) on pectinolytic softening of cucumbers. J. Food Sci. 26: 84.

Etchells, J.L., Bell, T.A., Fleming, H.P., Kelling, R.E., and Thompson, R.L. 1973. Suggested procedure for the controlled fermentation of commercially brined pickling cucumbers—the use of starter cultures and reduction of carbon dioxide accumulation. Pickle Pak Sci. 3: 4.

Etchells, J.L., Bell, T.A., Fleming, H.P., Kelling, R.E., and Thompson, R.L. 1974. Bloater chart. Published and distributed by Pickle Packers International, Inc., St. Charles, Ill.

Etchells, J.L., Borg, A.F., and Bell, T.A. 1968. Bloater formation by gas-forming lactic acid bacteria in cucumber fermentations. Appl. Microbiol. 16: 1029.

Fleming, H.P. 1979. Purging carbon dioxide from cucumber brines to prevent bloater damage—a review. Pickle Pak Sci. 6: 8.

Fleming, H.P., Etchells, J.L., Thompson, R.L., and Bell, T.A. 1975. Purging CO_2 from cucumber brines to reduce bloater damage. J. Food Sci. 40: 1304.

Fleming, H.P. and Pharr, D.M. 1980. Mechanism of bloater formation in brined cucumbers. J. Food Sci. 45:

Fleming, H.P., Thompson, R.L., Bell, T.A., and Monroe, R.J. 1977. Effect of brine depth on physical properties of brine-stock cucumbers. J. Food Sci. 42: 1464.

Fleming, H.P., Thompson, R.L., and Etchells, J.L. 1974. Determination of carbon dioxide in cucumber brines. Assoc. of Offic. Anal. Chem. 57: 130.

Fleming, H.P., Thompson, R.L., Etchells, J.L., Kelling, R.E., and Bell, T.A. 1973a. Bloater formation in brined cucumbers fermented by Lactobacillus plantarum. J. Food Sci. 38: 499.

Fleming, H.P., Thompson, R.L., Etchells, J.L., Kelling, R.E., and Bell, T.A. 1973b. Carbon dioxide production in the fermentation of brined cucumbers. J. Food Sci. 38: 504.

Fleming, H.P., Thompson, R.L., and Monroe, R.J. 1978. Susceptibility of pickling cucumbers to bloater damage by carbonation. J. Food Sci. 43: 892.

Forward, D.F. 1959. The respiration of bulky organs. In "Plant Physiology—a Treatise," Ed. Steward, F.C., Vol. 4A. Academic Press, New York.

Hodgman, C.D., Weast, R.C., and Selby, S.M. 1955. "Handbook of Chemistry and Physics," 37th ed. Chemical Rubber Publishing Co., Cleveland, Ohio.

Marshall, D.E. 1975. Density-sorting of green-stock pickling cucumbers for brine-stock quality and related studies. M.S. thesis. Michigan State Univ., East Lansing, Mich.

Marshall, D.E., Levin, J.H., and Heldman, D.R. 1973. Density sorting of green stock cucumbers for brine stock quality. ASAE paper 73-304.

Veldhuis, M.K. and Etchells, J.L. 1939. Gaseous products of cucumber pickle fermentation. Food Res. 4: 621.

Ms received 12/18/79; revised 4/13/80; accepted 4/24/80.

Paper no. 6135 of the journal series of the North Carolina Agricultural Research Service, Raleigh, N.C.

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

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture or North Carolina State Univ., nor does it imply approval to the exclusion of other products that may be suitable.