PURGING OF CO_2 FROM CUCUMBER BRINES TO REDUCE BLOATER DAMAGE

INTRODUCTION

BLOATER DAMAGE in brined cucumbers usually increases with concentration of dissolved CO_2 in the brine; the damage is accentuated with larger cucumbers and at higher incubation temperatures (Fleming et al., 1973a; Etchells et al., 1975). Microorganisms which produce large amounts of CO_2, such as coliform bacteria (Etchells et al., 1945), yeasts (Etchells and Bell, 1950) and heterofermentative lactic acid bacteria (Etchells et al., 1968), have been implicated as causes of bloater damage in natural fermentations as practiced commercially. Recently, however, Fleming et al. (1973a, b) and Etchells et al. (1975) found that CO_2 which originates from the cucumber, plus the small amount produced by the homofermentative lactic acid bacterium, *Lactobacillus plantarum*, is sufficient to cause serious bloater damage. Factors affecting CO_2 build-up and retention in the brine, such as brining depth and pack-out ratio, also influence bloater development (Etchells et al., 1975). Removal of dissolved CO_2 from brines by purging with nitrogen gas reduced or eliminated bloater damage (Fleming et al., 1973a). Brine circulation may also reduce build-up of CO_2 (Etchells et al., 1975).

Prompted by some of these findings, Etchells et al. (1973) developed a commercial procedure for the controlled fermentation of cucumbers brined in bulk. This process recently has stimulated considerable interest of research groups in pickling areas of the country, and efforts by briners to apply the process on a commercial scale. The process involves: (1) directing the fermentation by thorough washing of the cucumbers, chlorination and acidification of the cover brine, addition of sodium acetate as a buffer, and inoculation of the brine with a starter culture of *L. plantarum;* and (2) purging of dissolved CO_2 from the brine with nitrogen.

Present objectives were to: study factors affecting CO_2 removal from brines by purging with nitrogen; compare effects of nitrogen and air, as purging gases, on the fermentation and quality of the brine-stock cucumbers; and, compare the effectiveness of purging in reducing bloater damage in natural as compared to controlled fermentations. The controlled fermentation process was tested on a laboratory as well as a commercial scale. Larger sizes of cucumbers were used throughout these studies because of their greater susceptibility to bloater damage. Also, the trend in recent years has been toward the harvest of the larger sizes.

MATERIALS & METHODS

Brining

Pickling cucumbers (no. 3 size, 1½–2 in. diam) were brined according to the controlled fermentation process described for commercial use by Etchells et al. (1973). Brining was done in 5-gal, plastic pails and in 55-gal drums with adaptations of the above process for small containers according to Etchells et al. (1975). Brined cucumbers were inoculated after equilibration, usually 24–36 hr after the initial acidified cover brine and salt had been added and within 2 hr after adding the sodium acetate buffer. Inoculation was with *L. plantarum* WSO (4 billion cells/gal brined material) grown in cucumber juice broth (Fleming and Etchells, 1967) containing 5% NaCl. Salt was added to maintain the brine strength at 25° salometer (6.6% NaCl, w/w).

For natural fermentations, the cucumbers were brined to maintain 25° salometer NaCl without any further treatment. The brines were allowed to undergo fermentation by the natural microflora.

Ultraviolet lamps were placed 20 in. above the brine surface of open pails and drums to prevent growth of film yeasts (Etchells et al., 1975). For experiments with closed 5-gal pails, a "fermentation lock" was placed in each cover, through a rubber serum stopper. The lock sealed the brined material from the atmosphere, but prevented pressure build-up by permitting escape of gas. All fermentations were in duplicate, and all analytical and quality evaluations reported represent averages.

Brine analyses

Brines were sampled with sterile, 12-ml, plastic syringes (20-gauge needles) through rubber serum stoppers placed in the sides of the drums and pails. Titratable acidity (calculated as lactic acid), pH, NaCl and reducing sugars of the brine samples were determined by methods described or cited by Fleming et al. (1973a). Dissolved CO_2 was determined according to Fleming et al. (1974).

Evaluation of brine-stock

The active period of fermentation was usually completed within 1–2 wk, after which 50 or more cucumbers were cut and bloaters categorized as either balloon-, lens- or honeycomb-type (Jones et al., 1941; Etchells and Jones, 1951). Severity of cucumber damage was rated as slight, moderate or advanced (Fleming et al., 1973a; Etchells et al., 1973). Firmness was measured with a USDA Fruit Pressure Tester according to Bell and Etchells (1961); adjective ratings for such pressure tests on 1½–2 in. diam fruit are: 20 lb and above = very firm; 16–19 lb = firm; 11–15 lb = inferior; 5–10 lb = soft; 4 lb and below = mushy (devised by Etchells and Hontz, 1973).

Purging

In preliminary studies to determine factors affecting CO_2 removal, aqueous model solutions were purged with nitrogen. Sodium bicarbonate was added to 28 liters of distilled water for the desired concentration of CO_2 in an 11-in. diam × 35-in. high glass chromatography jar. The solution was then adjusted to the desired pH with lactic acid. A 54-in., coiled, polyethylene tube (¼ in. i.d.), perforated with 37 holes by a 27-gauge needle, was fastened securely to a plexiglass plate at the bottom of the jar and served as the sparger. Nitrogen was bubbled through at a rate of 740 ml/min.

To make spargers for the 5-gal pails and 55-gal drums, straight sections of polyethylene tubing (3/16 in. i.d.; 5/16 in. o.d.) were inserted 1–2 in. from the bottom of the containers, horizontally through rubber serum stoppers (5/8 in. diam) positioned in the sides of the containers. Three uniformly spaced holes were then made in the tubing in 5-gal pails, with a 27-gauge needle; and 7 holes were made for 55-gal drums. One end of the sparger that protruded through the container was heat sealed; the other end was connected to a flowmeter through which purging gas entered. The compressed nitrogen or air used for purging and the flowmeters were obtained from Air Products and Chemicals, Inc., Emmaus, Pennsylvania.

Solubilities of CO_2 in brines

Solubilities of CO_2 in 0–3M NaCl at 0–50°C (atmospheric pressure) were reported by Harned and Davis (1943) as "Henry's law constants." Their tabulated data were converted to mg CO_2/100 ml brine and graphed (Fig. 1) so that solubility of CO_2 within these ranges of conditions could be interpolated. Such interpolations may be further facilitated by replotting the solubility data in Figure 1 as a function of NaCl concentration at the desired temperature. Similar values may be calculated from solubilities expressed as "Bunsen absorption coefficients" by Bohr (1899), and later referred to by Quinn and Jones (1936).

The solubility of CO_2 in aqueous NaCl or in spent cucumber brine (pH 3.3) was estimated by bubbling CO_2 into each solution through a fritted glass gas dispersion tube until saturation was reached (usually 1 day or longer). Each solution, 3 liters, was contained in a 1-gal jar which was capped. The dispersion tube entered the cap through a rubber septum, and gas entered the solution 14 cm below the surface from the fritted region of the tube. Gas exited the jar through a 1-cm diam hole in the cap. All solutions were held at constant temperature under atmospheric pressure.

RESULTS & DISCUSSION

Solubility of CO_2 in brine

Solubilities of CO_2 in distilled water and in aqueous NaCl solutions, determined in this study, were within 3% of the values interpolated from the converted data of Harned and Davis (Table 1). The solubility of CO_2 in spent cucumber brine was essentially the same as that in aqueous NaCl solutions of similar concentrations and temperatures (Table 1). Clearly, NaCl in fermented cucumber brines ($pH < 4$) was the primary solute which governed CO_2 solubility. Therefore, solubilities of CO_2 shown in Figure 1 were assumed to be representative of solubilities in cucumber brines.

Changes in NaCl concentration or temperature of brines may affect bloater formation in cucumbers. For example, increased NaCl or temperature of a brine would lower CO_2 solubility (Fig. 1), causing more dissolved CO_2 to enter the gaseous state. It is not necessary for CO_2 concentration in the brine to exceed saturation for bloater formation to occur, however, as damage has been shown to occur early in the fermentation when the level of CO_2 was well below the saturation point (Fleming et al., 1973a).

Factors affecting CO_2 removal by nitrogen purging

Solubility of CO_2 in water is about 80 times that of nitrogen at 27°C (Hodgman et al., 1955). Bubbles of nitrogen introduced into the bottom of a carbonated solution or cucumber brine absorbed CO_2 as they rose through the solution. Air, which is about 80% nitrogen, and other gases of low solubilities in aqueous solutions probably would also sweep CO_2. But, nitrogen, because of its inertness and relatively low cost, has been the choice for most of our studies. Nitrogen has been used similarly to "strip" dissolved CO_2 from solutions during the freeze-concentration of citrus juices (Toulmin, 1959; Smith, 1963).

Rates of CO_2 removal from model systems were not greatly different at pH 4.5 and 3.5 (Fig. 2), but the rate of removal from a solution initially at pH 5.5 was considerably lower due probably to increased conversion of CO_2 to bicarbonate as the pH rose to 7. The pK_1 of carbonic acid is 5.94 in 1M NaCl (ca. 6%, w/v) brine at 25°C (Harned and Bonner, 1945). When the solution was buffered at pH 5.5, the rate of CO_2 removal was only slightly lower than that at pH 4.5 or 3.5. Rates of CO_2 removal were not appreciably affected by temperature (15 vs 23°C) or NaCl concentration (0, 6.6 or 13.2%) when solutions containing 92 mg CO_2/100 ml, pH 3.5, were purged (data not shown).

Based on the above pK_1 value, approximate percentages of CO_2 in brine solutions (ca. 6% NaCl) of the "total CO_2 content" (includes CO_2, H_2CO_3, HCO_3^-, and $CO_3^=$) at pH 3.5, 4.5, 5.0, 5.5, 5.94, 6.5 and 7.0 are 100, 96, 90, 73, 50, 22 and 8%, respectively. At these pH values the remainders in each instance are essentially in the bicarbonate form. Since only CO_2 can be absorbed into the nitrogen purging gas, it is suggested that pH 5.0 or lower be maintained during nitrogen purging for most efficient removal of CO_2. In controlled fermentations, the brine is acidified and then buffered at pH 4.7 (±0.2) prior to inoculation with the starter culture. In natural fermentations, however, initial brines may approach pH 6 or higher, especially if the water used to make the brine is unusually alkaline or some alkaline additive is present.

Design and placement of the nitrogen sparger are likewise important factors in the efficiency of CO_2 removal. For example, the size of orifice through which the purging gas passes

Table 1—Solubilities of carbon dioxide in aqueous solutions and in spent cucumber brines

NaCl (%)	Temperature (°F)	CO_2, mg/100 ml solution: Present study[a]	Harned and Davis[b]
		Distilled water	
0.00	90	118 (2.1)	120
		Aqueous NaCl	
6.90	60	141 (0.0)	142
7.00	90	91 (1.1)	90
		Spent cucumber brine[c]	Aqueous NaCl
2.88	80	123 (0.0)	122
5.87	80	109 (1.1)	109
11.64	80	87 (1.1)	88
17.22	80	70 (0.0)	71
6.40	60	148[d] (1.6)	145
6.45	70	125[d] (1.8)	122
6.25	80	107[d] (1.5)	107
6.10	90	95[d] (1.7)	93

[a] Values represent averages of 4–10 analyses. Standard deviations are given in parentheses.
[b] Values interpolated from the converted data of Harned and Davis (1943) plotted in Fig. 1.
[c] The cucumber brine was obtained after completion of controlled fermentation. Fermentation CO_2 was removed from the brine by nitrogen purging prior to carbonation. The brine, pH 3.3, was adjusted to the desired % NaCl prior to carbonation.
[d] These brines contained the cucumbers which had been fermented in them.

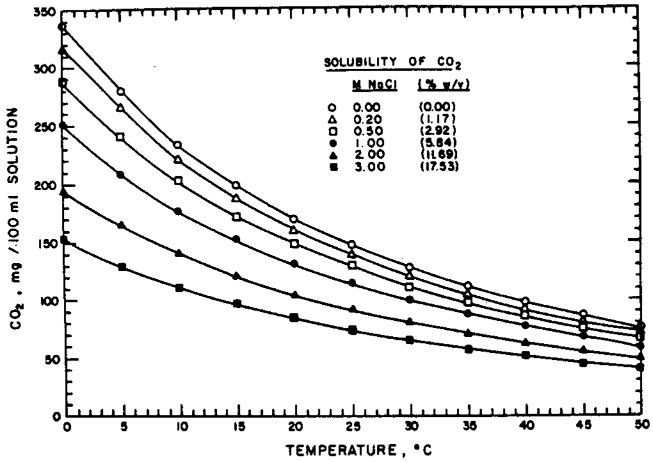

Fig. 1—Solubilities of CO_2 in water and in aqueous NaCl solutions from 0–50°C (32 to 122°F). Data are based on "Henry's law constants" reported by Harned and Davis (1943).

affects bubble size. Smaller bubbles provide more surface area per unit of purging gas than larger bubbles, and should be more efficient in removing CO_2 from the brine. The sparging conditions cited in the Materials & Methods section have been highly satisfactory for our use, but other systems may be more desirable for commercial operations.

Purging CO_2 from fermenting brines

Brine in the closed, 5-gal pails retained high concentrations of CO_2 during the active period of fermentation, and beyond (Fig. 3). CO_2 concentrations in open pails were from 30–40 mg/100 ml brine after 1 day, but decreased thereafter. Closed pails probably approximate conditions, with respect to CO_2 concentrations, in the lower regions of commercial brining tanks. CO_2 is retained longer at deeper brine depths (Etchells et al., 1975).

Effects of various nitrogen flow rates on CO_2 removal from brines of controlled fermentations in closed pails are shown in Figure 4. To illustrate the effect of purging on CO_2 removal, brines were not purged until after a 1-day equilibration. During this time, CO_2 diffused from the cucumbers to a level of about 40 mg/100 ml brine. In actual practice, immediate purging upon brining of the cucumbers is preferable, with the CO_2 concentration being maintained below 20 mg/100 ml brine (Etchells et al., 1973). Continuous purging at nitrogen flow rates of 5–100 ml/min reduced and maintained CO_2 concentrations in the brine below the initial values.

Purging of brines intermittently for 2 hr each day at 425 ml nitrogen/min also reduced CO_2 levels (Fig. 4). However, over 7 times as much nitrogen was used over a 24-hr period for intermittent purging as for continuous purging at 5 ml/min (Table 2).

Effect of purging on the quality of brined cucumbers

Controlled fermentations in closed pails. Percentages of balloon, honeycomb and total bloaters were reduced significantly

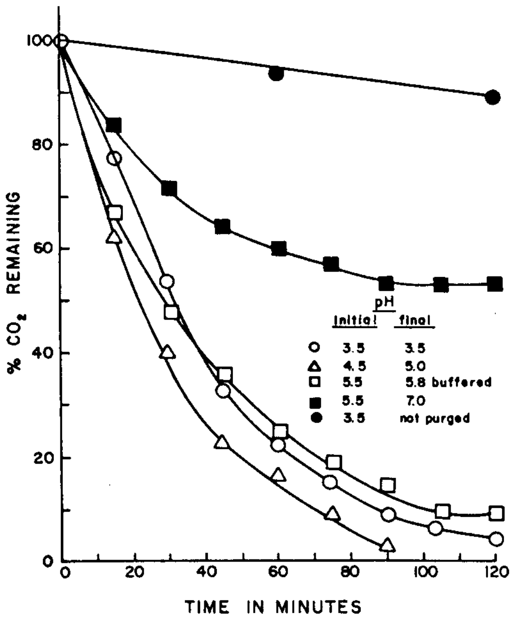

Fig. 2–Effects of pH on removal of dissolved CO_2 from water by nitrogen purging at 23°C (73°F). Initial CO_2 concentration was 139 mg/100 ml. The pH was adjusted with lactic acid except for the pH 5.5 buffered solution (□) which contained 0.2M acetic acid and 0.2M sodium acetate.

Table 2–Gas usage for intermittent and continuous nitrogen purging of cucumbers brined in 5-gal pails[a]

Purging method	Flow rate (ml/min)	Time purged per day (hr)	Gas volume used per day (liters)
Intermittent	425	2	51.0
Continuous	5	24	7.2
Continuous	25	24	36.0
Continuous	100	24	144.0

[a] Rates of CO_2 removal are shown in Fig. 4.

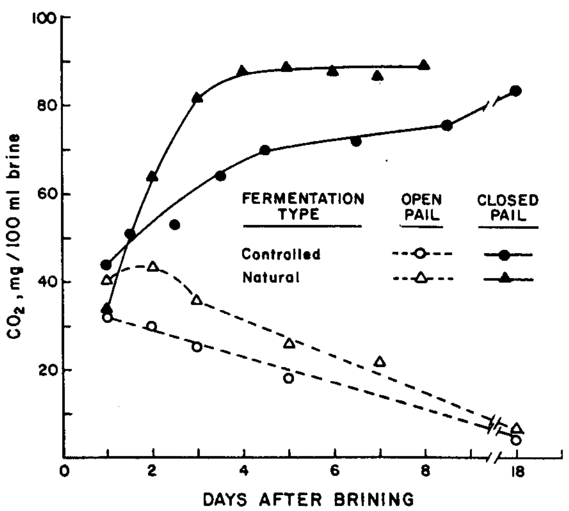

Fig. 3–Concentrations of dissolved CO_2 in open and closed, 5-gal pails of nonpurged fermentations. Controlled fermentations were inoculated 1 day after brining.

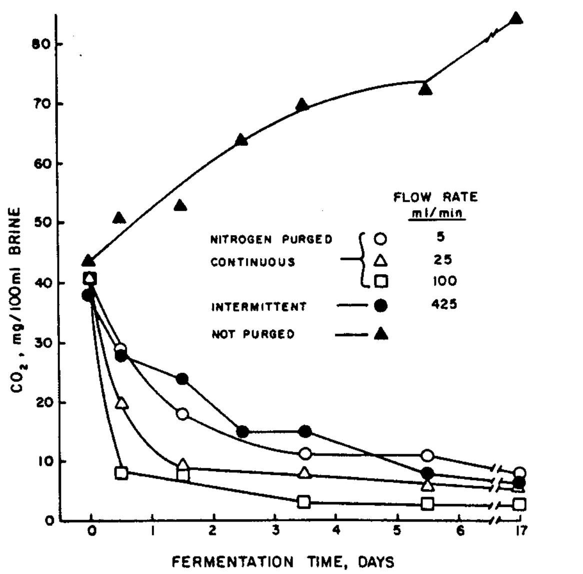

Fig. 4–Effects of nitrogen flow rates on removal of CO_2 from brines of controlled fermentations of cucumbers in 5-gal pails. For "intermittent," purging was for 2 hr daily.

Table 3—Effects of purging brines with nitrogen or air on controlled fermentation of cucumbers in closed, 5-gal pails at 32°C (90°F)

Treatment	Gas flow (ml/min)	Bloaters[a] Balloon (%)	Balloon (D)[c]	Lens (%)	Lens (D)	Honeycomb (%)	Honeycomb (D)	Total (%)	Color[b] Outside	Color[b] Inside	Pressure test (lb)	Brine analyses[a] pH	Acid (%)	Maximum CO_2[d] (mg/100 ml)
Nitrogen-purged														
Continuous	5	5	(S)	8	(S)	2	(S)	15	T	T	18.6	3.25	1.28	41(1)
	25	2	(S)	5	(S)	1	(S)	8	T	T	19.4	3.29	1.33	41(1)
	100	2	(S)	6	(S)	0	—	8	T	T	18.6	3.32	1.30	40(1)
Intermittent	425	9	(S)	5	(S)	1	(S)	15	T	T	19.6	3.30	1.31	38(1)
Air-purged														
Continuous	100	0	—	2	(S)	0	—	2	Sl. gray	Gray	17.0	3.35	1.18	38(1)
Intermittent	425	0	—	1	(S)	0	—	1	T	Sl. gray	19.4	3.31	1.24	40(1)
Not purged		31	(M-A)	10	(M)	43	(S-M)	84	T	T	17.8	3.34	1.35	84(18)
LSD 0.01		15		19		7		17			2.12	0.10	0.08	

[a] Brine samples analyzed 17 days after brining; cucumbers then cut and evaluated for bloater damage. Reducing sugar less than 0.05% in all brines.
[b] "T" refers to a typical color of salt-stock cucumbers which is light to dark olive-green outside and light straw inside.
[c] Letters in parentheses indicate the severity of bloating: S, Slight; M, Moderate; A, Advanced. When two letters are shown, the first indicates the degree of bloating in the majority of the cucumbers.
[d] Number in parentheses is the day after brining at which maximum CO_2 was attained. Purging was not begun until 1 day after brining; CO_2 in purged lots was highest prior to start of purging and decreased thereafter. See Fig. 3.

($P < 0.01$), and the degree of damage in those affected was less in brined cucumbers purged with nitrogen or air than in nonpurged controls (Table 3). Pressure test readings were slightly higher for nitrogen-purged (continuous or intermittent) and intermittently air-purged cucumbers than for nonpurged cucumbers ($P < 0.05$), due perhaps to the higher incidence of bloaters in the nonpurged lots; readings for continuously air-purged cucumbers were slightly lower ($P > 0.05$).

Nitrogen-purged and nonpurged cucumbers were not noticeably different in color; but the skins and internal flesh of air-purged cucumbers were gray (Table 3). The cured appearance (translucent flesh of the brine-stock cucumbers in contrast to the white, opaque internal flesh of the green fruit) at the time of evaluation (about 3 wk after brining) ranged from 55–100%. Air-purged cucumbers had a more cured appearance, while nitrogen-purged lots were not noticeably different from the nonpurged cucumbers.

When pails were opened, all brines were free of surface growth and had a clean, typical brine-stock odor, even when air was the purging gas. This is contrary to results when natural fermentations were purged with air as will be discussed below.

Natural fermentations in closed pails. Purging of natural fermentations in closed pails with nitrogen (Experiment I, Table 4) reduced the total percentage of bloaters, but the

Table 4—Effects of purging brines with nitrogen or air on natural fermentation of cucumbers in closed, 5-gal pails at 32°C (90°F)

Treatment	Gas flow (ml/min)	Bloaters[a] Balloon (%)	Balloon (D)[c]	Lens (%)	Lens (D)	Honeycomb (%)	Honeycomb (D)	Total (%)	Color[b] Outside	Color[b] Inside	Firmness rating	Brine analyses[a] pH	Acid (%)	Sugar (%)	Maximum CO_2[d] (mg/100 ml)
Experiment I															
Nitrogen-purged															
Continuous	100	18	(M-A)	8	(M)	13	(M)	39	T	T	Firm	3.42	0.48	0.27	33(1)
Air-purged															
Continuous	25	26	(A-M)	1	(M)	5	(M)	27	T	T	Soft	3.43	0.44	0.04	38(1)
	50	3	(A)	7	(M)	2	(S)	12	Sl. gray	Sl. gray	Soft	3.29	0.53	0.05	33(1)
	100	6	(A)	7	(M)	5	(M)	18	Gray	Gray	Soft	3.34	0.49	0.04	33(1)
Not purged		12	(A)	16	(M-A)	23	(S)	51	T	T	Firm	3.26	0.72	0.32	90(8)
LSD 0.01		20		29		10		31				0.34	0.19	0.25	
Experiment II															
Air-purged															
Intermittent	425	16	(S)	1	(S)	8	(S-VS)	25	T	T	Firm	3.05	0.89	0.05	67(4)
Not purged		34	(A)	2	(A)	40	(S)	76	T	T	Firm	3.05	1.11	0.09	103(5)

[a] Brine samples analyzed 7 days after brining in Experiment I and 15 days after brining in Experiment II; cucumbers cut after last brine sampling and evaluated for bloater damage.
[b] "T" refers to a typical color of salt-stock cucumbers which is light to dark olive-green outside and light straw inside.
[c] Letters in parentheses indicate the severity of bloating: S, Slight; M, Moderate; A, Advanced. When two letters are shown, the first indicates the degree of bloating in the majority of the cucumbers.
[d] Number in parentheses is the day after brining at which maximum CO_2 was attained. Purging was not begun until 1 day after brining; CO_2 in purged lots was highest prior to start of purging and decreased thereafter (See Fig. 3).

Table 5–Effects of purging brines with nitrogen or air on cucumbers fermented in open, 5-gal pails at 27°C (80°F)

Treatment	Gas flow (ml/min)	Quality of brine-stock cucumbers: Bloaters[a] Balloon (%)	(D)[c]	Lens (%)	(D)	Honeycomb (%)	(D)	Total (%)	Color[b] Outside	Inside	Pressure test (lb)	Brine analyses[a]: pH	Acid (%)	Maximum CO_2[d] (mg/100 ml)
Natural fermentation														
Air														
Intermittent	200	24	(A)	8	(M)	6	(S-M)	38	T	T	17.9	3.18	0.60	44(2)
Continuous	10	10	(A-M)	6	(M)	4	(M)	20	T	T	13.6	3.22	0.53	33(2)
Nitrogen														
Continuous	10	12	(M-A)	9	(S)	5	(M)	26	T	T	17.1	3.20	0.60	26(2)
Control														
Not purged		21	(A-M)	7	(M)	10	(M)	38	T	T	18.1	3.14	0.66	44(2)
Controlled fermentation														
Air														
Intermittent	200	0	–	0		0	–	0	T	Sl. pink	16.2	3.37	1.04	33(1)
Continuous	10	0	–	0		0	–	0	T	T	18.6	3.35	1.05	16(2)
Nitrogen														
Continuous	10	0	–	2	(M)	0	–	2	T	T	17.5	3.38	1.05	11(2)
Control														
Not purged		4	(S)	4	(M)	2	(S)	10	T	T	16.4	3.30	1.16	30(2)
LSD 0.01		20		14		13		14			2.08	0.29	0.17	

[a] Brine samples analyzed 26 days after brining; cucumbers then cut and evaluated for bloater damage. Reducing sugar less than 0.05% in all brines.
[b] "T" refers to a typical color of salt-stock cucumbers which is light to dark olive green outside and light straw inside.
[c] Letters in parentheses indicate the severity of bloating: S, Slight; M, Moderate; A, Advanced. When two letters are shown, the first indicates the degree of bloating in the majority of the cucumbers.
[d] Number in parentheses is the day after brining at which maximum CO_2 was attained. Purging was begun 3 hr after brining.

reduction was not as striking as was observed with controlled fermentations (Table 3). Continuous air purging resulted in soft cucumbers, due apparently to mold growth, which caused the termination of this experiment after only 7 days. Mold mycelia, and a heavy growth of film yeast, were present on the brine surfaces of all air-purged lots. Air-purged brines had an unpleasant odor, probably due to the surface growth. Both the exterior (skin) and the internal area (flesh and seed cavity) of the cucumbers, were slightly gray in some of the continuously air-purged lots (Table 4). No surface growth was detected in closed pails of nitrogen-purged or nonpurged cucumbers. The color and firmness of nitrogen-purged cucumbers were normal, and the brines had a clean, fermented odor.

Intermittent air purging reduced bloater damage and the color and firmness of the cucumbers were similar to those of the nonpurged cucumbers (Experiment II, Table 4). However, the brines were covered with film yeasts, and the brines had an undesirable odor usually associated with these yeasts. Again, no surface growth was present in nonpurged lots, and the brine had a clean, fermented odor.

Controlled and natural fermentations in open pails. Both nitrogen and air purging resulted in virtually bloater-free brine-stock in controlled fermentations contained in open pails (Table 5). However, purging of the natural fermentations had little effect on bloater damage.

Continuous air purging reduced firmness of cucumbers in natural fermentations. Intermittent air purging of controlled fermentations caused the flesh of some of the cucumbers to turn pink. No surface growth was visible on the brine of any of these pails due to the inhibitory effect of light from the ultraviolet lamps.

Controlled and natural fermentations in 55-gal drums. Table 6 summarizes the averaged data from 12 fermentations in 55-gal drums. Because the cucumbers, of necessity, were brined at various times, direct comparisons between treatments must be viewed with caution. However, nitrogen purging again reduced bloater damage in controlled fermentations, but did not appreciably reduce damage in natural fermentations. Reasons for the ineffectiveness of purging in reducing bloater damage in natural fermentations are presently under study. New, unpublished data suggest that the initial acidity and resultant low pH of the cover brine of controlled fermentations make cucumbers more responsive to the purging treatment.

Summary of brine-stock evaluations. Bloater damage, firmness, color and odor were primary factors used to obtain subjective ratings for quality of the brine-stock cucumbers. Table 7 summarizes these ratings for overall commercial acceptability of cucumbers brined according to treatments in Tables 3–6.

Table 6–Effect of purging brines with nitrogen on cucumbers fermented in open 55-gal drums at 27°C (80°F)

Treatment	No. of drums	Bloater damage: Balloon (%)	(D)[a]	Lens (%)	(D)	Honeycomb (%)	(D)	Total (%)
Natural fermentation								
Purged	5	28	(M-A)	5	(M-A)	23	(S-M)	56
Not purged	3	33	(A-M)	15	(S-A)	19	(S)	67
Controlled fermentation								
Purged	3	16	(S)	1	(S)	2	(S)	19
Not purged	1	42	(S-A)	5	(M-S)	8	(S)	55

[a] Letters in parentheses indicate the severity of bloating: S, Slight; M, Moderate; A, Advanced. When two letters are shown, the first indicates the degree of bloating in the majority of the cucumbers.

Brine level rise during active fermentation

The brine levels in 55-gal drums rose in controlled fermentations which were not purged (Fig. 5), and in nonpurged, natural fermentations (data not shown). The rise in brine level, termed "expansion volume," is due to formation of gas pockets inside cucumbers and a simultaneous loss of liquid from the cucumbers (bloater formation) due to pressure exerted on the flesh, as was noted earlier in gallon jars (Fleming et al., 1973a). The brine level did not rise in the purged, controlled fermentation (Fig. 5), and gradually dropped after 2 days. The brine level of the nonpurged fermentation also began to drop after about 3 days, probably due to filling of the bloated cavities with brine, and to evaporative losses. In the nonpurged fermentations, CO_2 concentration peaked (78 mg/100 ml) at about 4 days in samples taken near the bottom of the drum; whereas, at mid-depth, the CO_2 concentration peaked to a smaller amount (52 mg/100 ml) at about 2 days.

The relation between rise in brine level and bloater formation was noted earlier, as was the finding that bloater development begins during the first few days after brining, when fermentation is active (Fleming et al., 1973a). During this period, the buoyancy of the cucumbers increases greatly, and appreciably beyond that of fresh cucumbers initially placed in the brine solution. The buoyancy force created by severe bloater formation can break head boards and, often, the heavier 4 X 4 in. timbers that key down commercial-sized tanks. This problem is well known by briners in the pickle industry. Purging of CO_2 from the brine, by reducing bloater formation, would reduce such excessive pressures created in brining tanks.

Effects of purging on fermentation

Purging of controlled fermentations with either nitrogen or air did not greatly affect final brine acidities (Tables 3 and 5). Also, no important differences were noted in rates of acid production or in growth (determined by optical density of the brine, 650 nm) of *L. plantarum* due to purging with either nitrogen or air at the flow rates used.

Final acidities were more variable in natural (Table 4) than in controlled fermentations, as might be expected because of the variability of microflora in natural fermentations.

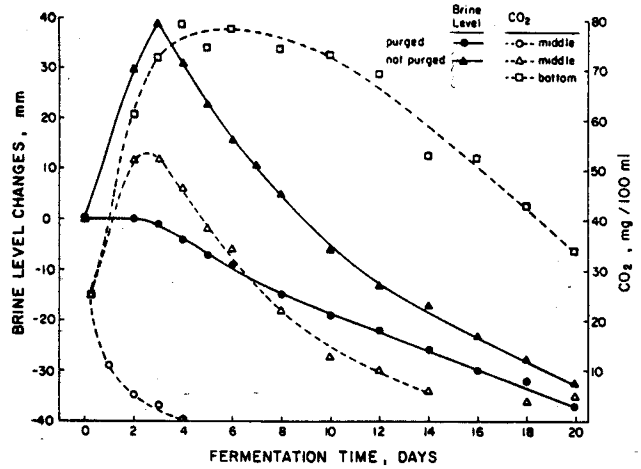

Fig. 5—Brine level changes and CO_2 concentrations in nitrogen-purged and nonpurged, controlled fermentations in 55-gal drums at 27°C (80°F).

Glacial acetic acid, added initially to the cover brines of controlled fermentations (6 ml/gal = ca. 0.23% acid, calculated as lactic), increased the final acidities (see e.g., Table 5). But, this added acid did not account entirely for the difference in final acidities between the two types of fermentations. The controlled fermentation was primarily homofermentative; whereas, various microorganisms in natural fermentations undoubtedly produced end products other than lactic and acetic acids.

Effects of purging on flavor of finished pickles

Samples of cucumbers from nitrogen-purged and nonpurged fermentations were desalted and packed in a dill-flavored cover liquor to finish at 3 to 4% NaCl and ca. 1% acid (added as

Table 7—Summary of brine-stock evaluations for fermentation and purging treatments[a]

Type of fermentation	Purging gas	No. of fermentations	Rating[b] Numerical avg	Rating[b] Adjective	Primary reasons for rating
Controlled	Nitrogen	13	8.0	Good	Slight to no bloater damage, firm texture, acceptable color and odor
	Air	8	7.6	Good	Slight to no bloater damage, firm texture, some slight gray and pink off colors to flesh
	Not purged	5	3.4	Poor	Excessive bloater damage
Natural	Nitrogen	9	3.4	Poor	Excessive bloater damage
	Air	12	2.3	Barely Acceptable	Soft texture, moderate to excessive bloater damage, off color and odor
	Not purged	9	1.7	Barely Acceptable	Excessive bloater damage

[a] This table summarizes data from 44 fermentations in 5-gal pails and 12 fermentations in 55-gal drums as given in Tables 3–6.
[b] Subjective evaluation of brine-stock for overall commercial acceptability. Adjective descriptions for numerical ratings are: 9–10 = Excellent; 7–8 = Good; 5–6 = Fair; 3–4 = Poor; 2 = Barely Acceptable; 1 = Not Acceptable. These ratings are probably lower than what most commercial briners would have given. They reflect standards which we have set in our efforts to provide a method for obtaining brine-stock cucumbers with virtually no defects.

acetic). After ca. 1 month of equilibration, the pickles were sliced, coded and tasted by a panel consisting of eight individuals. No important differences in flavor were noted between the nitrogen-purged and nonpurged cucumbers.

Controlled fermentations in commercial brining tanks

Several pickle companies have recently begun testing the controlled fermentation process under commercial conditions. One such company, with our direct assistance, used essentially the procedure of Etchells et al. (1973) for six commercial brining tanks (about 6,000-gal capacity each). No. 4 size (2–2¼ in. diam), hand-picked cucumbers were used in these experiments. The suggested procedure for nitrogen purging (Etchells et al., 1973) was modified as follows: the tanks were purged intermittently with either 55 or 100 cu ft/hr of nitrogen for 1 hr at 8-hr intervals during the first 4 days after brining, for 1 hr at 12-hr intervals on the 5th–7th days, and for 1 hr on the 8th and 9th days after brining. The cured brine-stock that showed no evidence of mechanical damage of the cucumbers prior to brining was evaluated by experienced judges, including one of the authors (JLE), and contained 3% balloon (S-M), 2% lens (S) and 2% honeycomb (S) bloaters (letters in parentheses represent the severity of damage, as in footnote 3, Table 3). The plant manager stated that these six tanks of brine-stock were the best he had seen during his 8 yr of brining experience at this location. Nonpurged natural fermentation of No. 4 size cucumbers averaged 25–35% serious damage due to balloon- and lens-type bloaters which the plant manager stated was typical for this size stock at his plant.

CONCLUSIONS

1. Removal of CO_2 from controlled fermentations by nitrogen purging of the brine greatly reduced or eliminated bloater formation. Purging of CO_2 from natural fermentations did not consistently reduce bloater damage.
2. Primarily because of its inertness, nitrogen is preferred over air as the purging gas. Air removed CO_2 from brine, but, resulting effects on quality factors such as loss of firmness and discoloration of the cured cucumbers cause us to strongly recommend that air not be used for purging.
3. Film yeasts were not a problem in closed, tight containers either not purged or purged with nitrogen, due apparently to the inert atmosphere created over the brine surface. Air purging of cucumbers in closed containers resulted in brine surface growth of film yeast and mold.
4. Neither nitrogen nor air purging, at the levels used, appreciably affected the rate of acid production or final brine acidities in controlled fermentations.
5. Removal of CO_2 from brine by purging reduces buoyancy pressures created by bloated cucumbers, and, therefore, should serve to relieve excessive pressures on containers in which cucumbers are brined.
6. Commercial application of the controlled fermentation process resulted in greatly improved brine-stock quality.

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