

BRINING OF OXYGEN-EXCHANGED CUCUMBERS IN PILOT TANKS: A STATUS REPORT*

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CAUTION: Oxygen exchange technology is still in the experimental stage. We strongly urge that the oxygen exchange procedure not be used commercially at this time. Improperly handled, the procedure can result in problems of product spoilage and safety due to the possibility of undesirable microorganisms being drawn into the cucumbers. The industry will be informed of further developments that may make oxygen exchange of practical use in the pickling of cucumbers and other vegetables.

ABSTRACT

The practical benefits of replacing the internal gases of fresh cucumbers with oxygen (O_2 exchange) prior to brining were evaluated in pilot tanks. Open-top, wood tanks (ca. 850 gal) and a closed-top, fiberglass tank (1,170 gal) were used for the tests. Oxygen-exchanged cucumbers displayed the following unique brining properties in both types of tanks: 1) there was a rapid (1 day) drop in brine level, which represented 3 to 7% of the cucumber volume; 2) there was a rapid (1 day) drop in buoyancy of the cucumbers; and 3) visual cure of the cucumber tissue was rapidly (within 3 days) acquired. Acquisition of the above properties in O_2 -exchanged cucumbers is thought to be merely an acceleration of the gradual changes associated with curing in normal brine storage of non-exchanged cucumbers.

Unwashed, O_2 -exchanged cucumbers brined and N_2 purged in open-top wood tanks bloated during fermentation; while *washed*, O_2 -exchanged cucumbers brined and N_2 purged in a closed, fiberglass tank did not. Possible reasons for these effects are discussed.

Rapid acquisition of cure may be advantageous for brine storage of cucumbers in the closed tank now being developed for the pickle industry. However, further laboratory and pilot studies are needed to fully resolve potential problems such as bloater damage before O_2 -exchange technology can be recommended for commercial use. The research reported herein actually uncovered complexities that already have resulted in several fundamental studies. These complexities and possibilities for commercial application of O_2 -exchange technology for cucumber brining are discussed.

INTRODUCTION

Many factors have been shown to influence bloater formation in brined cucumbers including cucumber variety and growing conditions and the type of fermentation. Fleming and Pharr (1980) and Fleming et al. (1982) found that by varying the composition of the gas within the fresh cucumbers, they were able to greatly influence susceptibility of the cucumbers to bloater damage during brine fermentation. They proposed a mechanism for the formation of bloaters based on these and earlier studies.

In a related study, Fleming et al. (1980) found that exchange of the internal gases of fresh cucumbers with pure oxygen immediately before brining caused the brined cucumbers to acquire the translucent appearance of fully cured brine stock within a few days, as compared to several months for nonexchanged cucumbers. Furthermore, the density of O_2 -exchanged cucumbers more rapidly approached that of the brine, resulting in a more rapid loss in buoyancy. And finally, the cucumbers were less susceptible to bloater formation during brine fermentation. Thus, it appeared that O_2 exchange of the cucumbers as a prebrining treatment might offer important advantages in the brining of the cucumbers.

The purpose of the present research was to determine if the apparent practical benefits of O_2 exchange could be demonstrated on a pilot scale.

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MATERIALS AND METHODS

Cucumbers

Size no. 3 cucumbers (1½-2 inches in diameter), free of serious disease and mechanical injury, were used in these studies. The cucumbers were locally grown and were brined the day after harvest.

Experimental design and brining tanks

In July 1980, eight pilot, wooden tanks (about 850 gal each, 81 inches diameter × 38 inches deep) were used for a pilot brining study. The tanks previously had been coated on the interior with fiberglass to prevent leaking, but slight leakage still occurred in some. Duplicate tanks were used for each of four treatments: not O₂ exchanged — not purged; not O₂ exchanged — N₂ purged; O₂ exchanged — not purged; and O₂ exchanged — N₂ purged.

In July 1981, one pilot fiberglass tank (model CM-CFV-5, 60 inches diameter × 96 inches deep, manufactured by Warner Fiberglass Products) was used in a study to determine the effect of washing cucumbers before brining on bloater damage in the O₂-exchanged cucumbers. Further details on this tank, which was closed to the atmosphere, are given in our companion paper (Fleming et al., 1983). The cucumbers were washed with an Osborn washer. This was a follow-up of the 1980 experiments in which the O₂-exchanged cucumbers were seriously bloated. The 1980 cucumbers were not washed, and this was thought to be a possible cause for the bloater damage in O₂-exchanged fruit. The general flow chart for the 1980 and 1981 experiments is given in Figure 1.

Tanking procedure

In the 1980 experiment, cucumbers were weighed and filled into the open-top, wooden tanks by use of a fork-lift truck (Fig. 2). In the 1981 experiment, weighed cucumbers were conveyed through the manway of the fiberglass tank by a conveying system similar to that described by Fleming et al. (1983). In both cases, the tanks were partially filled with water to cushion the fall of the cucumbers. The water was then drained off and discarded before gas exchange and brine addition.

Oxygen exchange

Our first pilot studies with O₂ exchange were in 1980 using open-top wooden tanks (Fig. 2). After loading the cucumbers and draining the water, the tanks were covered with a plastic sheeting (Fig. 2c). Oxygen was introduced through perforated (¼-inch diameter holes drilled 1 ft apart), ¼ inch diameter polyethylene tubing that was secured in a circular arrangement to the bottom of the tank. The O₂ was metered in at 95 standard cubic feet per hour (SCFH) for 2 hr, and then brine was added while continuing O₂ flow until the cucumbers were covered with brine. Then, the plastic cover was removed from the tanks.

In 1981, one pilot, closed-top fiberglass tank, outfitted for zero head space operation, as schematically illustrated in Figure 3, but otherwise similar to that described by Fleming et al. (1983), was used. In this configuration, a head device as such was not necessary since the plexiglass man-

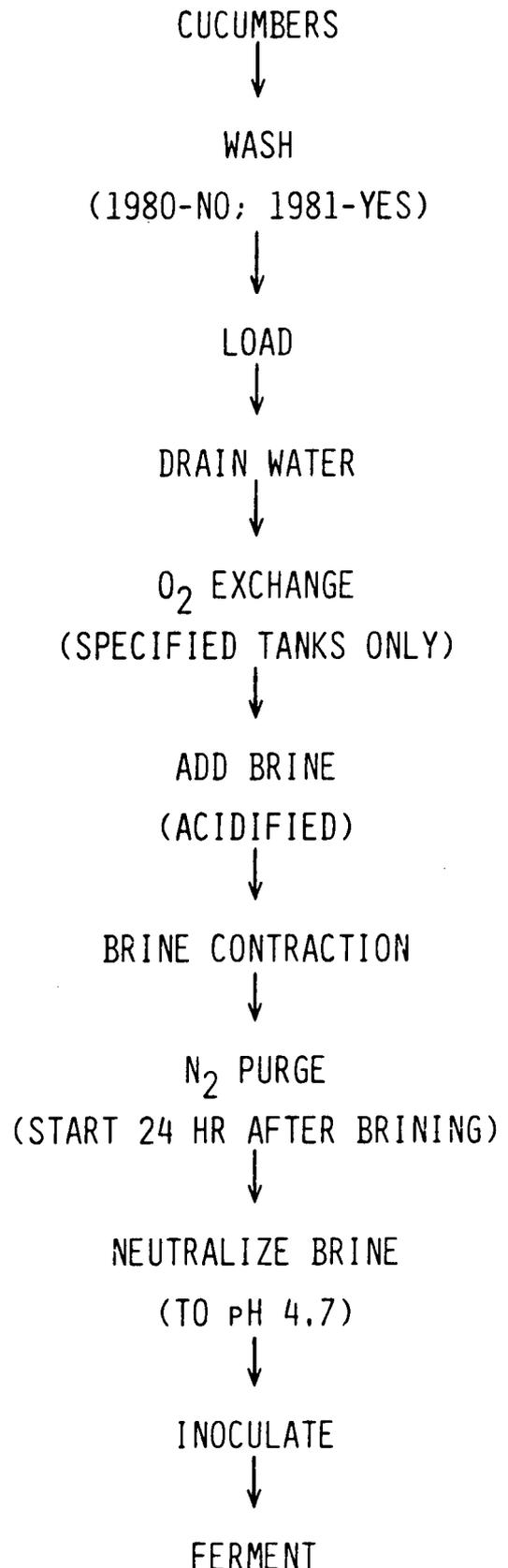


Fig. 1. Flow chart for O₂ exchange and brining of cucumbers in 1980 (eight wood tanks) and in 1981 (one fiberglass tank).

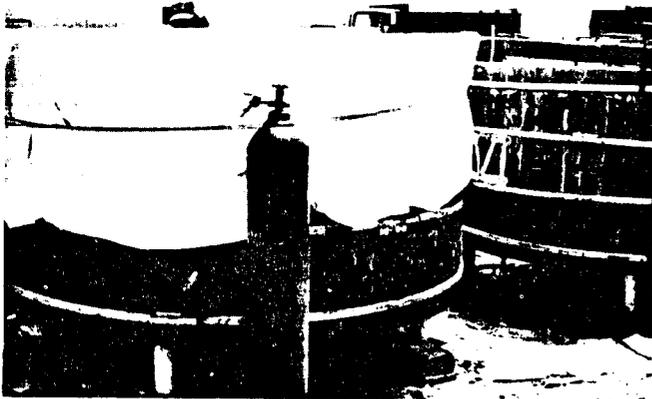
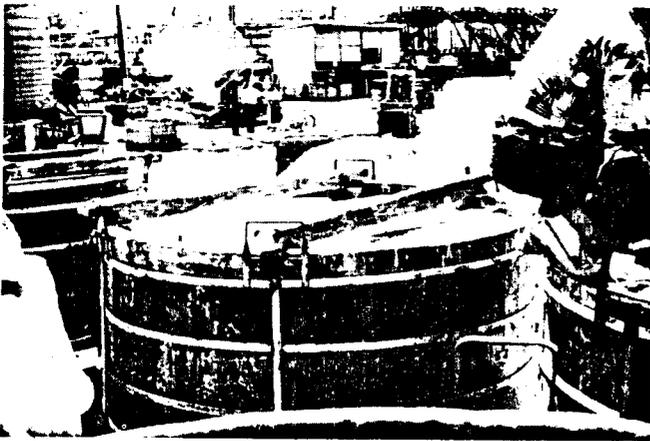
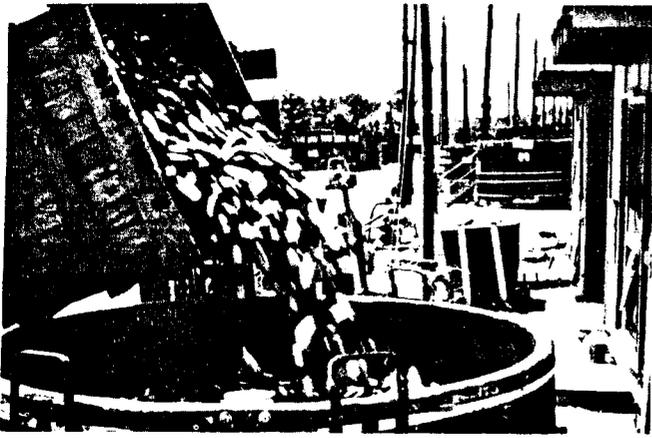


Fig. 2. Pilot, wood tanks used in the 1980 brining experiment: a) Loading with a forklift truck; b) Tank headed with wooden timbers; c) Tank covered with a plastic sheet for O_2 exchange, O_2 tank in the foreground.

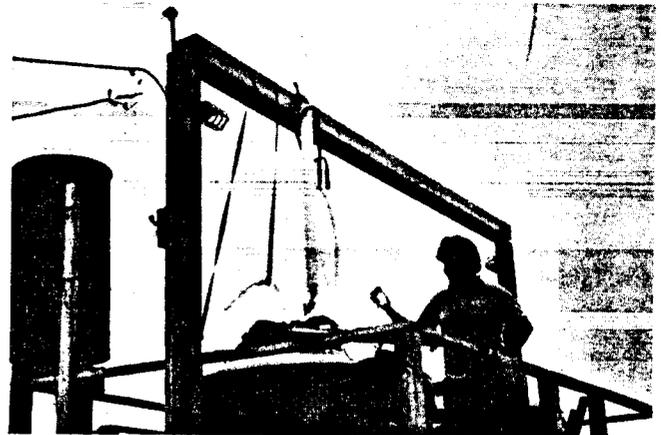
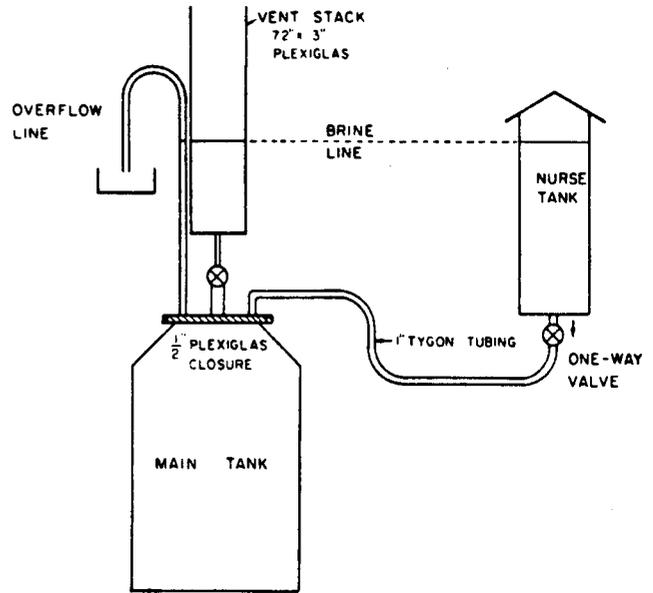


Fig. 3. Zero headspace principle for brine tank anaerobiosis in a pilot fiberglass tank (1981): a) Schematic, not drawn to scale; b) Picture.

hole cover also kept the cucumbers submerged. In order to provide a supply of brine for rapid uptake by the O_2 -exchanged cucumbers, a nurse tank was connected to the main fermentation and holding tank by means of tygon tubing (1 inch diameter) as shown. The nurse tank supplied additional brine as required by gravity feed and consequently the brine level in the vent tube stack and nurse tank dropped simultaneously. The nurse tank was fiberglass, 24 inches in diameter and 48 inches in height, and had sufficient capacity to supply the total brine uptake required. The connecting line was equipped with a one-way PVC flow valve to prevent the main tank contents from being forced back into the nurse tank. The main tank closure was attached to the flanged manhole opening by 24 equally spaced, $\frac{3}{8}$ -inch stainless steel bolts and was equipped with PVC bulkhead fittings for the nurse tank line, vent stack, a sampling port, and overflow line. The overflow line was included in the event of rapid gas formation resulting from an out-of-control fermentation and served primarily as a safety device. In order to prevent loss of brine under normal circumstances, the tygon tubing (1 inch diameter) overflow line was looped to a position above the brine level as

illustrated in Figure 3. A container was provided to catch any overflow so that actual brine uptake could be determined. The details of the vent stack are given by Fleming et al. (1983). After draining the filling water from the loaded cucumbers, O₂ was introduced at a rate of 250 SCFH for 1 hr through a tube mounted in the tank bottom as described above for the wooden tanks. After the 1 hr O₂ addition, O₂ concentration in the gas surrounding the cucumbers exceeded 98% by volume as determined by the O₂ electrode method (Portable DO meter, model 2110, Delta Scientific Corp., Lindenhurst, NY) described by Potts and Fleming (1979). The acidified cover brine was then added to the main tank and nurse tank, to a level of 30 to 36 inches above the tank closure and brine uptake observations initiated.

Brining

The pack-out ratio, cucumbers:brine, was about 60:40. The cover brine contained 0.5% CaCl₂ and 0.4% acetic acid (added as 200 grain vinegar), to equilibrate at 0.2% and 0.16%, respectively. The initial salt concentration was 11.4% (40° S). For the open-top tanks (1980), dry salt was added in 80- and 60-lb increments on the 4th and 6th days, which resulted in 20° S salt at equalization. For the closed tank (1981), dry salt was added to the cover brine when it was withdrawn from the tank for neutralization (see below), to equalize at 22° S.

Brine drop

The drop in brine level was monitored during the first day after brining. In open-top tanks (1980), the brine drop was read from a ruler that had been mounted on a heading cross-timber. In the closed tanks (1981), the brine drop was monitored by a graduated scale on the nurse tank. As brine was taken up by the cucumbers, additional brine was drawn from the nurse tank and the common brine level in the nurse tank and vent stack dropped. This resulted in the absence of gas headspace in the main tank at all times. After about 1 day, the brine no longer dropped, since these cucumbers had been O₂ exchanged.

N₂ purging

Since we were interested in monitoring the initial drop in the brine level, purging was not begun until 24 hr after brining. Then, brines were purged continually at a rate of about 15 SCFH N₂ with the side-arm purger until the fermentation was complete, as indicated by absence of fermentable sugars and no change in brine acidity over a period of several days. A few days after brining when fermentation was very active, foam overflowed from the vent stack (Fig. 3b). The foaming subsided after addition of 100 ml of Antifoam C (Dow Corning).

Neutralization of brine

About 24 hr after brining, the cover brine was neutralized to pH 4.7 with a calculated and weighed quantity of dry sodium hydroxide. The sodium hydroxide was dissolved in 5-10 gal of brine. For the open tanks, the dissolved sodium hydroxide was slowly pumped into the flow of brine from the side-arm purger. For the closed tank, the brine was pumped from the fermentation tank into an adjacent mix-

ing tank after 24 hr, and the sodium hydroxide was slowly added while stirring. The adjusted brine was inoculated and then pumped back into the fermentation tank.

Inoculation

Brines were inoculated after neutralization with 28 g of AFerm 771 (Microlife Technics, Sarasota, FL), which resulted in billions of cells of *Lactobacillus plantarum* per gallon of brined material. The inoculum was slowly poured into the side-arm stream in the open tanks (1980). The inoculum was added to the cover brine after it was withdrawn from the closed tank and adjusted to pH 4.7 with sodium hydroxide (1981 experiment).

Fermentation

All brines were allowed to ferment to completion, which required about 2 wk. The brine temperature during fermentation was about 80° F.

Brine analyses and product evaluation

Analyses of brines for CO₂, pH, titratable acidity, reducing sugar, and salt; and product evaluation for bloater damage, firmness, visual cure, and soft centers were made as previously described (Fleming et al., 1983).

Visually cured, fresh pack hamburger dill chips by O₂ exchange

Size no. 2B (1 $\frac{1}{8}$ to 1 $\frac{1}{2}$ inches diameter) cucumbers (180 lbs) were O₂ exchanged (1 hr at 25 SCFH) in a 50-gal plastic drum. A dill-flavored, acidified cover brine was added and the drum allowed to stand overnight. The cucumbers were then sliced ($\frac{3}{8}$ inch thick), packed into 1-gal jars with the above cover brine, and pasteurized. A control lot of cucumbers was not O₂ exchanged, but was otherwise treated similarly. After about 10 days, the O₂ exchanged and the untreated lot were evaluated by a taste panel of 17 individuals. The panelists were asked to determine the odd sample in a triangle comparison test. Each panelist made two attempts to distinguish differences in the coded products. In one test, nonexchanged cucumbers were the odd sample, and in a second test, O₂-exchanged cucumbers were the odd sample.

RESULTS

Open-top, wood tanks (1980)

The brine level of O₂-exchanged cucumbers began to recede within the first hour after brine addition, as expected. The drop in the level of O₂-exchanged cucumbers reached $\frac{1}{8}$ to $\frac{1}{4}$ inches during the first 18 hr, which amounted to 25 to 36 gal. This drop was equivalent to 4.9 to 7.2% of the volume of the cucumbers. The level dropped only $\frac{1}{8}$ to $\frac{1}{16}$ inch in nonexchanged cucumbers (3 to 7 gal, equivalent to 0.5 to 1.4% of the volume of the cucumbers). Leakage of the tanks caused slight inaccuracy in these figures, but greater brine drop in O₂-exchanged cucumbers than in nonexchanged cucumbers was apparent. Also, the drop was similar to that found in laboratory studies.

All evidence during the first 3 days after brining indicated that the O₂ exchange treatment was having the same effect that we noted earlier in laboratory studies. Headboards in O₂-exchanged tanks floated freely, indicating the absence of buoyancy pressure. Oxygen-exchanged cucumbers were visually cured, while nonexchanged cucumbers were not. There was considerable buoyancy pressure against the headboards in nonexchanged tanks, and the cucumbers were raw in appearance. After about 4 days, however, buoyancy pressure was noted in the O₂-exchanged tanks and the cucumbers taken from underneath the headboards were severely bloated.

The cucumbers in all eight tanks fermented normally, and there were no important differences among tanks as indicated from final brine analyses (Table 1). The fermentation was complete within 2 wk. The dissolved CO₂ concentration reached 70 to 80 mg/100 ml brine in O₂-exchanged, nonpurged tanks and 47 to 63 mg/100 ml brine in nonexchanged, nonpurged tanks (Fig. 4). The CO₂ in purged tanks was below 30 mg/100 ml brine within 2 days after brining and never exceeded this concentration (Fig. 4).

TABLE 1.

Effect of N₂ purging and O₂ exchange on brine chemistry of unwashed cucumbers brined in open-top, wood tanks (1980)

Tank no.	Treatments*		Final brine analyses		
	O ₂ exchanged	N ₂ purged	pH	Acidity (%)	Sugar (%)
4	-	-	3.20	0.85	0.0
5	-	-	3.15	1.10	0.0
1	-	+	3.16	0.77	0.0
8	-	+	3.11	0.93	0.0
3	+	-	3.31	0.80	0.0
12	+	-	3.22	0.85	0.0
2	+	+	3.04	0.82	0.0
7	+	+	3.20	0.84	0.0

*A "+" indicates that the treatment was imposed, a "-" indicates that it was not.

Two weeks after brining, the tanks were opened and the cucumbers evaluated. Oxygen-exchanged cucumbers were severely bloated in three of four tanks, purged and nonpurged (Table 2 and Fig. 5). The damage was decidedly more severe than in the nonexchanged, nonpurged cucumbers. The nonexchanged, purged cucumbers were only slightly damaged. Oxygen-exchanged cucumbers were 96-100% visually cured, while nonexchanged fruit were only 38-50% cured (Table 2 and Fig. 5). There were no apparent differences in cucumber firmness and in the presence of soft centered cucumbers in any of the tanks.

Samples of bloated cucumbers were examined microscopically for the presence of bacteria within the cucumber tissue. Bacteria, predominantly small cocci, were observed within the intercellular spaces of mesocarp tissue of the cucumbers. A milky appearance occurred within the flesh of some O₂-exchanged cucumbers. A milky exudate, heavily laden with bacteria, could be pressed from the internal flesh of these cucumbers.

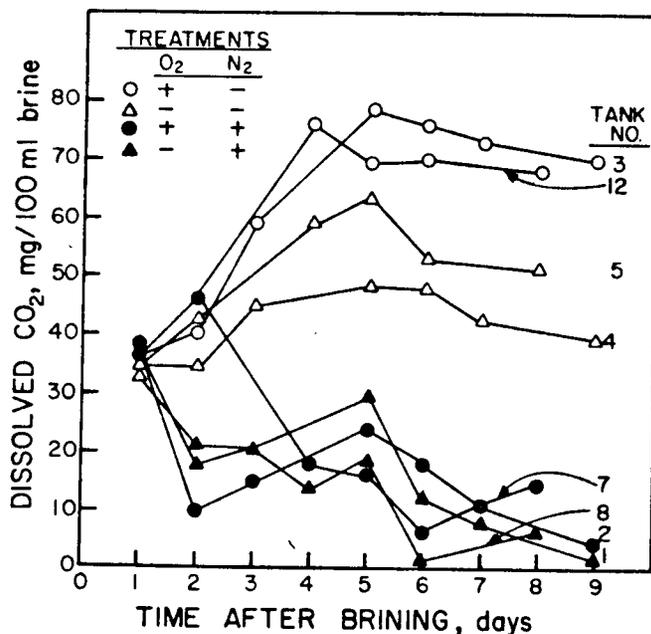


Fig. 4. Carbon dioxide concentration in the brines of purged and nonpurged fermentations in pilot wood tanks.

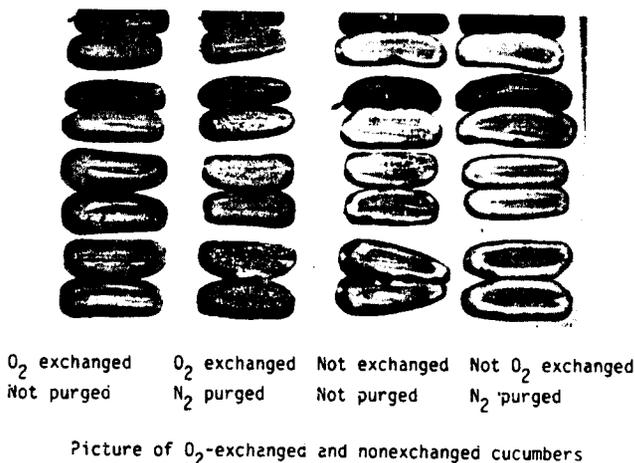


Fig. 5. Appearance of brined cucumbers 2 weeks after brining in wood tanks.

Closed-top, fiberglass tank (1981)

Drop in the brine level was monitored in the nurse tank. The level dropped a total of 23.2 gal over a 12 hr period before purging was begun, which represented about 3.3% of the cucumber volume.

The cucumbers fermented normally as illustrated in Figure 6. The CO₂ concentration never exceeded 30 mg/100 ml, since the brine was continually purged.

The tank was emptied by brine floatation 1 month after brining. Quality of the cucumbers in mesh bags compared to those loose in the tank was evaluated (Table 3). Some of the cucumbers contained in the neck of the tank (about 1/2 bu) were severely bloated. Beyond this depth, however, damage was not serious. Cucumbers sampled from the top 1/3 of the tank were slightly bloated, but damage in the middle and bottom 1/3 of the tank was almost negligible. The

cucumbers were 100% visually cured and were of acceptable firmness (Table 3). Soft centers were found in 10-55% of the cucumbers.

The firmness of the cucumbers was maintained during storage at 22° S (the same brine strength as during fermentation) and at 45° S during storage for 6 months at 78-80° F (Table 4). After 12 months, the firmness at 22° S had been reduced by 2 lbs and at 45° S by 1 lb.

Rapid cure of fresh-pack hamburger dill Chips by O₂ exchange

Fresh cucumbers were O₂-exchanged and covered with dill flavored cover liquor as described in the Materials and Methods section. The cucumbers were fully cured, visually, within 24 hr. Hamburger dill chips prepared from these cucumbers and nonexchanged cucumbers were evaluated by a 17-member taste panel. The chips prepared from O₂-exchanged cucumbers were fully cured and similar in appearance to chips prepared from fully fermented cucumbers. The chips from nonexchanged cucumbers appeared as raw, fresh-pack chips. The panelists were not allowed to see the products, but were asked to distinguish chips from the two treatments by taste, in duplicate triangle tests to distinguish the odd sample. The panelists correctly identified the odd sample in only 13 out of 34 comparisons, which is considerably less than the number of correct responses required for statistical significance at the 0.05 probability level (Kramer and Twigg, 1970).

DISCUSSION

The pilot studies reported herein confirmed certain of our earlier laboratory research (Fleming et al., 1980) which indicated that O₂-exchanged cucumbers display unique brining properties. Oxygen-exchanged cucumbers, when brined, acquired the visual appearance of fully cured brine stock within a few days. The cucumbers lost buoyancy and the brine level dropped during this period. However, to our surprise, the cucumbers were severely bloated in our first pilot test in wood tanks. The cucumbers in this test were not washed before brining, whereas in the earlier laboratory studies they were. In the second pilot test in a closed, fiberglass tank, the cucumbers were washed before O₂ exchange, and the cucumbers did not bloat.

Considerable fundamental research has been undertaken as a consequence of the severe bloater damage observed in our first pilot test. It was necessary to understand why the cucumbers bloated before we could judge the potential use of O₂ exchange on a practical basis. The following discussion is intended to summarize what we now know about O₂ exchange and how this information may be applied in the closed tank technology being developed in cooperation with the pickle industry (Fleming et al., 1983).

Fundamental knowledge

Fresh cucumbers contain about 75% N₂, 5% CO₂, and 20% O₂ (Fleming and Pharr, 1980). The fresh cucumber tissue is about 5-7%, by volume, intercellular gas spaces in which most of this gas is located (Jorge, 1978). This en-

trapped gas results in the tissue having a raw, white, uncured appearance. Oxygen exchange of the tissue results in replacement of the natural gases with O₂. When the cucumbers are covered with a brine solution, the O₂ is rapidly converted to CO₂ due to respiration of the cucumber tissue, leaving only N₂ and CO₂ in the cucumber. Now CO₂ is about 80 times more soluble than O₂, so much of the CO₂ formed dissolves in the liquid of the cucumber tissues. This causes the gas pressure in the intercellular spaces to decrease, and actually form a vacuum which reaches a maximum after about 1 hr (Corey et al., 1983). Simultaneously, a drop in the brine level can be observed. The vacuum causes liquid to be drawn into the tissue from the surrounding brine. When the gas spaces no longer exist, the tissue loses its raw, opaque appearance and takes on the translucent appearance of visually cured brine stock. Unfortunately, the vacuum within the cucumber also causes bacteria that may be present in the brine or on the fruit to be drawn into the tissue, where they may grow (Daeschel and Fleming, 1981). We think that entrance of certain unidentified, undesirable bacteria into the cucumbers in the 1980 pilot study, when the cucumbers were not washed, was the cause of the severe bloater damage. Furthermore, we think that the cucumbers in the 1981 experiment did not bloat because the washing treatment removed most of these bacteria.

Effects of the O₂ exchange treatment

1) *Rapid drop in brine level.* The rapid drop in brine level of O₂-exchanged cucumbers is merely an acceleration of a gradual drop that occurs during normal brine storage of cucumbers due to liquid filling the internal gas spaces of the cucumbers. By causing this drop to occur initially, the necessity of later brine addition could be avoided. This factor could be particularly useful in the closed tank concept as presently viewed. After the cucumbers are fully fermented, the tank could be secured without the need for continual brine addition to insure maintenance of the brine above the level of the cucumbers. Without O₂ exchange, the brine will continue to gradually drop, necessitating periodic brine additions. It is important that the brine not drop below the cucumbers near the top of the tank to avoid spoilage that could occur in fruit not submerged.

2) *Rapid drop in buoyancy.* Fresh cucumbers are highly buoyant when they are brined. This is because the cucumbers are less dense than the brine, due partially to gas entrapment in the cucumbers and partially to presence of salt in the brine. The buoyancy force can cause physical damage to the cucumbers near the top of the tank, depending upon the tank depth. The tank top must be of sufficient strength to compensate for this force. Oxygen exchange can be used to reduce the buoyancy force of the cucumbers. Thus, physical damage to the cucumbers near the top of the tank, and the force required to restrain the cucumbers under the brine can be reduced by O₂ exchange.

3) *Rapid visual cure.* Some packers have indicated that their customers require that hamburger dill chips be visually cured. Several months of brine storage may be required for visual cure to be completed. Thus, the raw appearance could be undesirable if one wishes to process the brine-stock early. Some packers indicate that the raw appearance

TABLE 2.

Effect of N₂ purging and O₂ exchange on the quality of unwashed cucumbers brined in open-top, wood tanks (1980)

Tank no.	Treatments*		BLOATER INDEX				Cure (%)	Firmness (lbs)	Soft centers (%)
	O ₂ exchanged	N ₂ purged	Balloon	Lens	Honeycomb	Total			
4	-	-	3.0	0.0	2.6	5.6	55	22.3	0
5	-	-	5.9	0.4	2.5	8.8	50	22.5	4
1	-	+	0.4	0.0	0.8	1.2	45	23.4	0
8	-	+	0.4	0.0	0.2	0.6	38	22.3	6
3	+	-	18.9	0.6	0.4	19.9	100	23.0	4
12	+	-	44.2	0.2	2.8	47.2	96	21.8	2
2	+	+	2.2	0.3	0.5	3.0	96	21.6	2
7	+	+	22.6	0.4	0.4	23.4	95	23.0	2

*A "+" indicates that the treatment was imposed, a "-" indicates that it was not.

TABLE 3.

Effect of tank location on brine stock quality of washed, O₂-exchanged cucumbers brined in a closed-top, fiberglass tank (1981)

Containment of brined cucumbers	Tank position	BLOATER INDEX				Cure (%)	Firmness (lbs)	Soft centers (%)
		Balloon	Lens	Honeycomb	Total			
Mesh bags	Top	2.3	0.4	1.1	3.2	100	20.3	13
	Middle	1.6	0.0	0.0	1.5	100	20.4	15
	Bottom	0.9	0.4	0.0	1.2	100	20.4	10
Loose	Top	5.6	3.0	0.2	8.8	100	19.5	12
	Middle	0.4	0.0	0.1	0.5	100	20.6	12
	Bottom	0.0	0.0	0.2	0.2	100	21.0	12

TABLE 4.

Firmness changes in washed, O₂-exchanged cucumbers fermented in a closed-top, fiberglass tank and stored at 22 and 45 °S in closed containers*

Storage time (months)	Brine strength (°S)	Firmness	
		lbs	Coefficient of variation
1 (initial)	22	20.4	9.5
6	22	20.0	14.7
12	22	18.4	12.1
6	45	21.2	10.4
12	45	19.0	14.9

*The fermented cucumbers were evaluated for firmness after 1 month of storage in the closed tank (initial), after the tank was unloaded. Samples of the brine stock were then held at 22°S (the original brine strength) or 45°S (obtained by adding dry salt in increments over a period of 7 days). The brine stock was held in duplicate, 5-gal pails (closed) for 6 months at 78-80°F. The pails were then opened and the brine stock evaluated for firmness (20 cucumbers from each pail). The remaining brine stock was then repacked into duplicate, 1-gal glass jars from each pail, and the jars were then held for an additional 6 months.

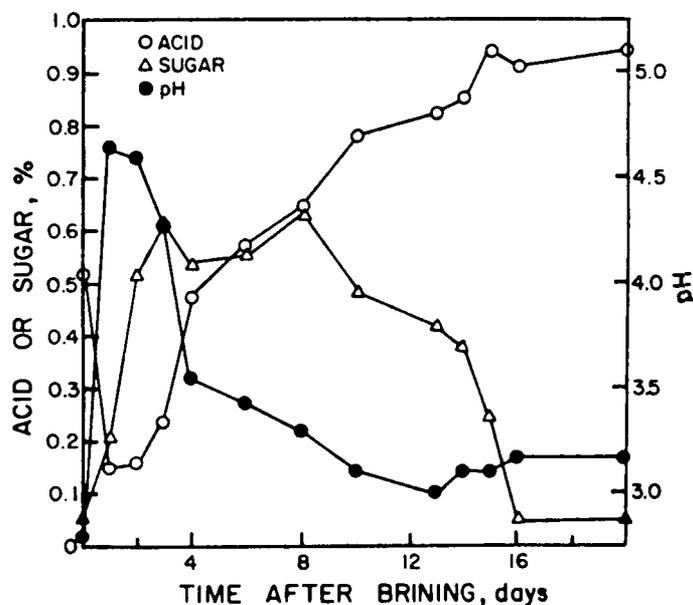


Fig. 6. Chemical changes during fermentation of O₂-exchanged cucumbers in a pilot, fiberglass tank.

is no problem. They simply heat the sliced cucumbers, which drives the gas from the tissue. Oxygen exchange could eliminate the uncured appearance, and the visually cured brine-stock cucumbers could be processed immediately after fermentation. In fact, the visual cure characteristic of fermented cucumbers can be achieved with fresh-pack cucumbers as shown in this study. Since fermentable sugars remain in fresh-pack cucumbers, however, the cucumbers must be pasteurized. We observed no flavor differences in fresh-pack hamburger dill chips prepared from O₂-exchanged cucumbers as compared to nonexchanged cucumbers.

4) *Reduced requirement for purging.* In laboratory studies using washed cucumbers, bloater damage in O₂-exchanged cucumbers was greatly reduced even when they were not purged (Fleming et al., 1980). At the time, we thought that the need for purging might be eliminated by the O₂ exchange treatment. The fact that severe bloater damage resulted in our pilot studies, even when the cucumbers were purged, indicates that further control is needed before O₂ exchange can be used on a commercial scale. Since we now know that bacteria can be drawn into O₂-exchanged cucumbers from the surrounding brine, we may be able to prevent the bloater problem noted in the 1980 pilot study. Washing or sanitizing the cucumbers could solve the problem. If so, the need for purging could be reduced or eliminated. Whether such treatments can be rendered effective on a commercial scale has yet to be fully established. The fact that the washed, O₂-exchanged cucumbers in our 1981 pilot study were not seriously bloated gives us some encouragement. However, these cucumbers were purged. Further pilot tests are needed to establish the possible benefits and problems of O₂ exchange before judgment is made on full-scale commercial use of O₂ exchange technology.

No problem was observed in retention of firmness of the O₂-exchanged cucumbers during storage at 22 or 45° S (Table 4). We are unsure if the 10-15% soft centered cucumbers in the single tank of the 1981 experiment (Table 3) were influenced by the O₂ treatment. There was no evidence, however, that O₂ exchange influenced soft center development in the eight-tank experiment of 1980 (Table 2).

Zero headspace concept for the fermentation tank

The concept of zero headspace on a fermentation tank with an accompanying nurse tank was demonstrated to function. However, for a single tank, the cost-to-benefit ratio may not be justified. The components chosen in this study were not ideal in that the PVC check valve to prevent back flow of brine to the nurse tank was not preloaded and, therefore, allowed some back flow before closing. Consequently, the nurse tank contents were contaminated with brine from the main tank and growth of microorganisms of the type usually found in pickle tanks from which sunlight has been excluded occurred. It is obvious then that the brine surface in the nurse tank must be maintained anaerobic under these circumstances.

In multiple tank operations as would occur in commercial tank yards, zero headspace techniques may offer significant advantages. Only one nurse tank would be neces-

sary to supply brine to any number of main tanks through a manifold system equipped with appropriate controls to maintain the brine level at the proper height in the vent stacks of individual tanks. It would not be necessary to maintain an anaerobic head on each tank, and head devices would not be required. However, longer vent stacks could be required to contain foam generation, and a considerable investment in controls and monitoring devices including overflow catch containers would be required to maintain a brine uptake history on individual tanks in the system.

ACKNOWLEDGMENTS

The authors wish to thank the many individuals and companies who have thus far participated in this project. These individuals and their contributions are given in the acknowledgments to a companion paper in this issue (Fleming et al., 1983). Special thanks are due to M. A. Daeschel for his initial microscopic observation of bacteria within O₂-exchanged, brined cucumbers.

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