PURGING CARBON DIOXIDE FROM CUCUMBER BRINES TO PREVENT BLOATER DAMAGE—A REVIEW

H. P. FLEMING

Food Fermentation Laboratory, U. S. Department of Agriculture, Science and Education Administration, Agricultural Research, Southern Region, and North Carolina Agricultural Research Service, Department of Food Science, North Carolina State University, Raleigh, NC 27650

ABSTRACT

Purging is a simple, practical means of preventing bloater damage in brined cucumbers. In the procedure, dissolved carbon dioxide in the fermenting brine is removed by bubbling nitrogen, inert gas, or air through the brine. Nitrogen or inert gas is recommended for use in purging brines; air will effectively prevent bloater damage, but its use may cause problems with brine-stock quality such as poor texture and off flavors and colors.

This review gives background information on development of the purging concept, explains the principle of purging, and gives guidelines and precautions for a successful purging operation. Areas that are not fully understood are discussed with the intent of stimulating further research.

INTRODUCTION

Bloater damage has been a source of serious economic loss to the pickle industry for decades. The problem has increased in the last 15 years or so due largely to increased demand for large cucumbers and the trend toward mechanical harvesting with resultant harvest of larger cucumbers. Large cucumbers are more susceptible to bloater damage than small ones. Bloater damage is caused by a buildup of carbon dioxide (CO_2) in the brine, which results in gas pockets inside the cucumbers. Carbon dioxide in the brine originates from the cucumber tissue and from microbial activity in the brine.

Controlled fermentation and purging of brines to prevent bloater damage are recent developments which have received considerable attention within the pickle industry. Although further research and engineering are needed to realize the full potential of these developments, the industry already is being influenced significantly from the farm level through processing and marketing of the finished pickle products. Higher yields of brine-stock cucumbers can now be expected from the larger sizes of cucumbers, which heretofore were extremely susceptible to bloater damage. Thus, these recent brining methods are timely for the farmer who has been forced to harvest more large fruit because of the current limitations of mechanical harvesters. Briners are being pressured to consider using these methods because of the improved quality and yields. Buyers of brine-stock cucumbers are now asking if the stock was purged, and if so, how, and if controlled fermentation was used.

Purging of CO_2 from brines, in particular, has received much attention since its introduction into the industry in 1972, especially by quality control supervisors and brine yard superintendents. Since then, the volume of brined cucumbers that is purged has increased annually. It is estimated that over half of the large cucumbers brined in the United States are now purged. Diminished, perhaps, is the mystique of the "old brine master" who tasted brines to determine if things were progressing satisfactorily and kicked the sides of the brining tanks to determine if the bubbles breaking the surface would yield to him insights that were not readily obvious to those who held him in such awe. The new generation of briners can show results in dollars and cents, which impresses the board of directors whether or not they understand the scientific basis for purging and controlled fermentation.

Briners must exercise caution, however, to avoid pitfalls that often attend new developments. In the food industry, the effect of even the smallest change in a product on the quality and wholesomeness for human consumption must be considered first; only then can economics be considered.

The purpose of this review is to give background information on development of the controlled fermentation process, with emphasis on purging which is an integral part of the original process. General scientific principles, advantages and precautions that should be considered by users or potential users of purging will be discussed. The review will deal only briefly with economic and engineering aspects of purging. Other aspects of the controlled fermentation process, including use of cultures and buffer additives, will not be dealt with fully herein.

PRINCIPLE OF PURGING

Carbon dioxide can be effectively removed from fermenting cucumbers by bubbling nitrogen (N_2) gas through the brine. Air and other gases will also efficiently remove CO_2 from the brine, but N_2 is recommended.

As N_2 is introduced near the bottom of the brine solution, bubbles of N_2 rise through the solution, absorbing dissolved CO_2 (Fig. 1). Carbon dioxide diffuses from the brine into the

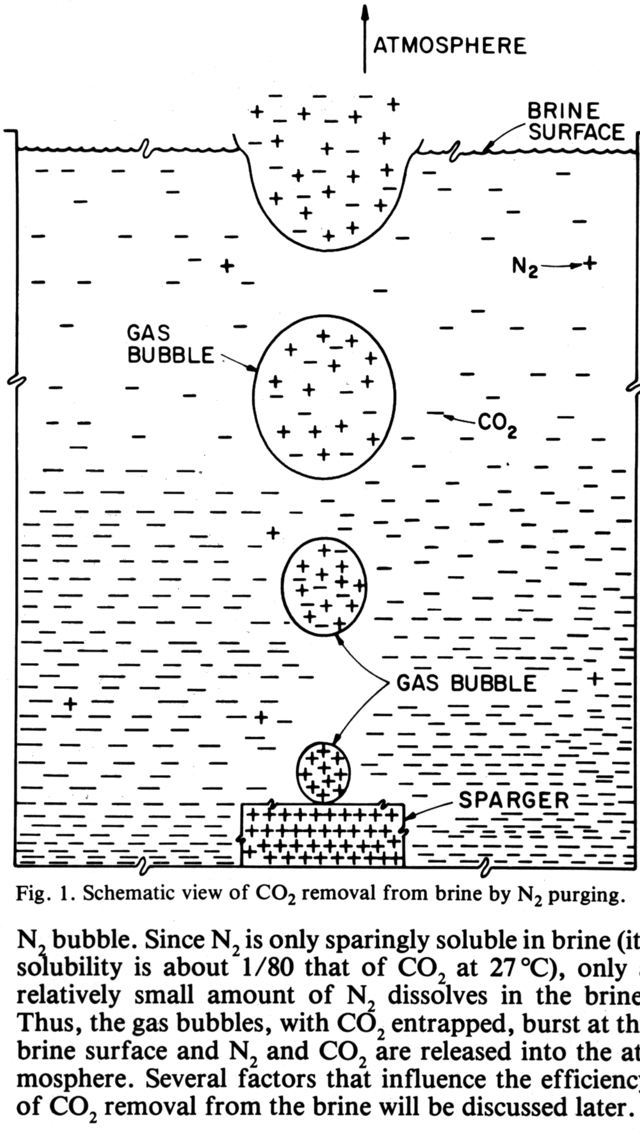

Fig. 1. Schematic view of CO_2 removal from brine by N_2 purging.

N_2 bubble. Since N_2 is only sparingly soluble in brine (its solubility is about 1/80 that of CO_2 at 27 °C), only a relatively small amount of N_2 dissolves in the brine. Thus, the gas bubbles, with CO_2 entrapped, burst at the brine surface and N_2 and CO_2 are released into the atmosphere. Several factors that influence the efficiency of CO_2 removal from the brine will be discussed later.

HOW PURGING GOT STARTED

It may seem strange that such a simple procedure as purging brines to prevent bloaters required so long to be discovered. Our only consolation is that many discoveries, when viewed retrospectively, seem simple and long overdue. Numerous scientists deserve credit for uncovering scientific principles that led to the purging development.

In 1939, Veldhuis and Etchells (1) reported that gas trapped inside bloated cucumbers was of the same approximate composition as the gas that evolved from the brines. They concluded that gas was produced within the cucumbers and by microorganisms in the brine. Then, in 1943, Etchells and Jones (2) reported that salting at high brine strengths caused limited growth of lactic acid bacteria, but extensive growth of yeasts and certain salt-tolerant coliform bacteria. Low levels of salt favored growth of lactic acid bacteria, with limited growth of yeasts. In a concurrent paper (3), they reported that high salt treatments resulted in low levels of acid, high amounts of CO_2, and a comparatively large proportion of bloaters. They concluded, therefore, that yeasts were the cause of bloating, due to production of large amounts of CO_2. Numerous studies on the types of yeasts active in fermenting brines followed (4-7). In the 1950's, several researchers reported means of controlling yeast growth by the addition of sorbic acid (8-13).

In 1968, however, Etchells et al. (14) reported that certain gas-forming lactic acid bacteria also can cause bloater damage. In a study on bloater damage in overnite dill pickles, yeasts were excluded from the brines by the addition of sorbic acid, but numerous gas-forming lactic acid bacteria were present. Recalling the earlier advent of pure culture fermentation of cucumbers in 1964 (15), Etchells et al. (unpublished) theorized that a sure means of controlling bloater damage was at hand. Well, the theory held if one added "non-gas-forming" lactic acid bacteria to pasteurized small cucumbers in capped glass jars, as was done in the pure culture process. It was deemed impractical, however, to heat the large amounts of cucumbers necessary for bulk brining in commercial operations. Therefore, we chose to control growth of natural microflora in the cover brine and cucumber surface with the use of chlorine and acetic acid. In a critical brining experiment under the supervision of Dr. J.L. Etchells (Doc) in the fall of 1969 (unpublished), cucumbers were sanitized, acidified, and brined in a 40-gal plastic onion drum and inoculated with a pure culture of *Lactobacillus plantarum*. Only the added culture was detected in the fermentation brine; no yeasts or other bacteria were observed. The fermented cucumbers were severely bloated!

Doc had the mixed reaction of surprise, shock, and excitement, realizing on the one hand that we had not reached the promised land, but on the other hand that some more variables had been eliminated and others obviously had not been considered. His enthusiasm pervaded the laboratory as we were determined to learn more about the mechanism of bloater formation. We were still convinced that CO_2 produced during brining caused bloater damage. Two questions occupied our immediate attention: How can we measure CO_2 in the brine? Where does the CO_2 originate?

Previously, CO_2 produced during fermentations was measured by trapping the gas that evolved from the surface of brines (1). In the present instance, however, the fermentation did not appear to be of the vigorous, "gassy" type with bubbles breaking the surface. Thus, it became obvious that we should measure the dissolved CO_2 in the brine. Initially, we used the method of the Association of Official Analytical Chemists (16) recommended for alcoholic beverages. The method was time-consuming and awkward for our purposes, however, so we eventually developed our own procedure for laboratory use (17). Somewhat later we adapted the Harleco method, which is now used extensively by the pickle industry for monitoring commercial brines (18).

We determined that CO_2 in fermenting cucumbers originates from two previously ignored sources (Fig. 2): the non-gas-forming lactic acid bacteria and the cucumbers themselves (19). The CO_2 from these sources

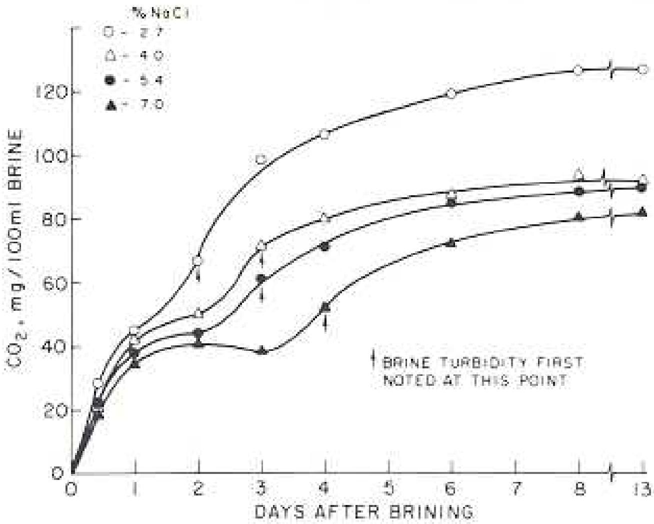

Fig. 2. Production of CO_2 in the fermentation of brined cucumbers. CO_2 appears in the brine from two sources: first CO_2 diffuses from the cucumbers and then is produced by microbes in the brine (from Fleming et al., 19).

was shown to be sufficient to cause bloater damage (20). Although *Lactobacillus plantarum* is loosely classified by microbiologists as a "non-gas-former," it produces sufficient CO_2 in cucumber fermentations to be significant.

In commercial fermentations, however, the yeasts remain an extremely important source of CO_2, since they may proliferate under conditions favorable for their growth. Thus, yeasts and lactic acid bacteria are two major microbial sources of CO_2 in fermenting cucumbers. Products of their fermentation are listed in Table 1.

TABLE 1.

Products from the fermentation of cucumbers by lactic acid bacteria and yeasts.[a]

Fermentable sugars	Microorganism	Products
Glucose and Fructose	Lactic acid bacteria	Lactic acid ($CH_3CHOHCOOH$)
		Acetic acid (CH_3COOH)
		Ethyl alcohol (CH_3CH_2OH)
		Carbon dioxide (CO_2)
	Yeasts	Ethyl alcohol (CH_3CH_2OH)
		Carbon dioxide (CO_2)

[a]Lactic acid is by far the major product from growth of *Lactobacillus plantarum* (a homofermentative bacterium), which is sold in cultures for fermenting cucumbers. However, this bacterium also produces small amounts of the other compounds listed, including CO_2. Certain other lactic acid bacteria, called the heterofermentative type, produce lactic acid as the major product, but also relatively high amounts of CO_2 and other compounds shown. Yeasts, if grown in the absence of air, as in cucumber fermentations, produce large amounts of ethyl alcohol and CO_2. If grown aerobically, yeasts produce primarily CO_2.

Now for the third question: How do we get rid of the CO_2? We were using the lactic acid bacterium that produces the least amount of CO_2, and we knew of no practical means of removing CO_2 from the cucumbers. It seemed logical, therefore, that we would have to remove the CO_2 produced by the bacteria and cucumbers from the brine solution mechanically. In our first efforts, we used 1-gal jars of brined cucumbers and successfully purged brines with N_2 through a fritted-glass gas dispersion tube, producing bloater-free brine stock (20). Later tests included brine circulation (21) and vacuum treatment of the brine (Etchells et al., unpublished results). All of these methods offered a means of reducing bloater formation when sufficient CO_2 was removed, but N_2 purging seemed to be the most practical and economical method and has occupied most of our attention.

The research on purging of brines is a classic example of the practical benefits that can accrue from cooperative research by industry and government. The Research Committee of Pickle Packers International, Inc., chaired by I.D. Kittel (1967-68), L.J. Turney (1969-71), D.H. Wallace (1972-73), and M.D. Orloff 1974-76), gave us invaluable encouragement during development of the purging concept and assistance in setting up initial commercial tests. L.H. Hontz and his employer, the Mount Olive Pickle Company (Mount Olive, NC), were especially cooperative in providing space and assistance in building of "mini" environmental chambers and in basic brining studies before scale up for commercial-sized operations. D.H. Wallace and his employer, the Atkins Pickle Company (Atkins, AR), were both extremely helpful in adapting the controlled fermentation procedure and the purging concept to commercial use, beginning with the first commercial-scale tests in 1972. R.L. Sellars and R.S. Porubcan of Chr. Hansen's Laboratory (Milwaukee, WI) were vitally involved in these tests and provided cultures for the fermentations. The Research Committee was informed of the progress of our work through annual progress reports starting in 1967. The first public disclosure of purging occurred in May, 1972, at a presentation to the Institute of Food Technologists (22). Representatives of several pickle companies (M.L. Lingle, Atkins Pickle Company; L.J. Turney, Paramount Foods; J. Cook, M.A. Gedney; P. Palnitkar, Vlasic Foods, Inc.; J.L. Segmiller, H.J. Heinz) discussed implications of the work after the paper was presented.

Publication of the purging procedure and the entire controlled fermentation process did not occur until 1973 (23), which is a typical delay resulting from required scientific reviews and administrative approval. Interestingly, the word of success in bloater control got out and enthusiasm for the new information could not be contained by the bounds of scientific and government delays. Even secrecy entered the thoughts of some, which heated enthusiasm still more. We could not have created this enthusiasm with presentations, publications, or otherwise. This was a "happening" that just occured, in spite of us. We are indeed grateful to have been a part of what since has become a minor revolution in the brining of cucumbers. Numerous industry people and scientists at other universities are continuing to contribute to the purging concept. Several publications (19, 20, 23-28) and a patent (29) on the purging process have appeared since our original report in 1972.

ADVANTAGES AND DISADVANTAGES OF PURGING

The advantages and disadvantages of purging need to be considered before a company makes any decision on the extent to which it should use the purging process. Some of these considerations are listed in Table 2.

TABLE 2.

Advantages and disadvantages of purging brined cucumbers.

Advantages
Less pressure damage to brine tanks and headboards.
Greater yields, especially from large cucumbers.
Less tank space required because of greater yield of pickles.
Improved quality.
Less costs in grading of brine stock.
Savings in salt and labor costs in handling and brining the cucumbers.
Disadvantages
Expense of purging.
More technical knowledge required.

One very noticeable advantage of purging is the reduction in the number of tanks that must be reheaded during brining because their heading timbers were burst by the pressures from bloated cucumbers (Fig. 3). Comparatively little pressure is exerted on the head-

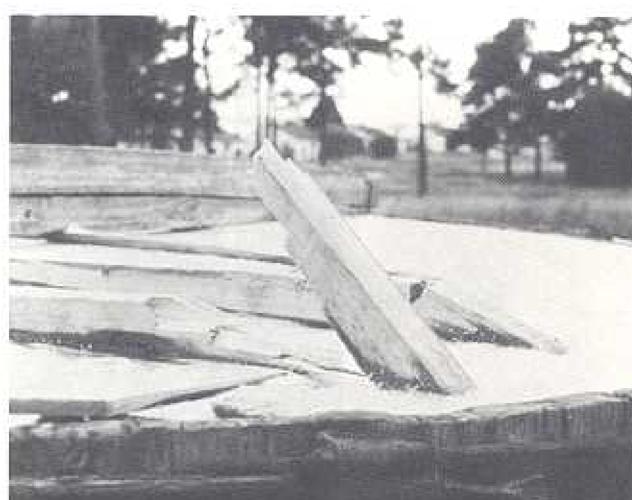

Fig. 3. Breakage of headboards of a brining tank because of the increased buoyancy pressure of bloated cucumbers. The tank was not purged.

boards of purged tanks (Fig. 4).

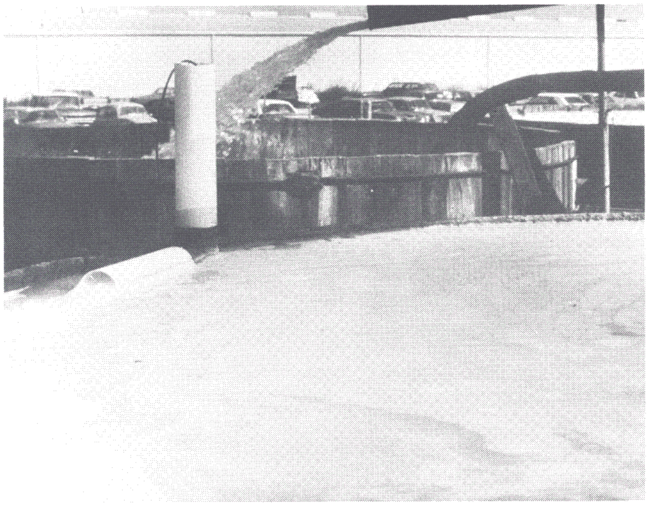

Fig. 4. Surface of brine being purged with a side-arm purger. Compliments of Mount Olive Pickle Company, Inc.

Purging can greatly increase brine-stock yields, depending on the extent of bloater damage that normally occurs in unpurged cucumbers, which varies among companies and geographically. Increases in yields of 10 to 50% or more in sound brine stock have been reported. Yield increases are especially great with cucumbers 1.5 inches or more in diameter. The increase in yield means that one can obtain the same amount of sound brine stock from fewer tanks, or that more brine stock can be handled with the same number of tanks. Obviously the quality of the brine stock is improved with the reduction of bloater damage (Fig. 5). Badly bloated brine stock is normally diverted to relish manufacture, resulting in its devaluation compared to sound stock, which can be used for more valuable products such as hamburger dill chips. The improved quality resulting from purging is especially noticeable with large sizes of cucumbers used for hamburger dill chips, which are judged by strict standards by institutional users. Grading costs are lower for purged stock because the cost of hand removal of bloated chips is reduced. Savings also result from the use of less salt and the lessened disposal problems, and from lowered labor costs for transporting the cucumbers and tanking and untanking the brine stock.

The expense of purging is an obvious disadvantage, although it can be more than compensated for in an efficient purging operation. The cost of purging generally is lower per bushel of brined cucumbers when large volumes of cucumbers are involved. Small briners, in general, will realize a greater expense in purging than will large briners, for N_2 gas is less expensively obtained in greater quantities. Personnel with technological skills and engineering knowledge are required to set up and maintain an efficient purging operation. Some briners have indicated that purging has caused a shortage of brine stock for relish use. Unbloated stock probably results in increased yields of relish stock of improved quality, however, and this "shortage" is not a disadvantage.

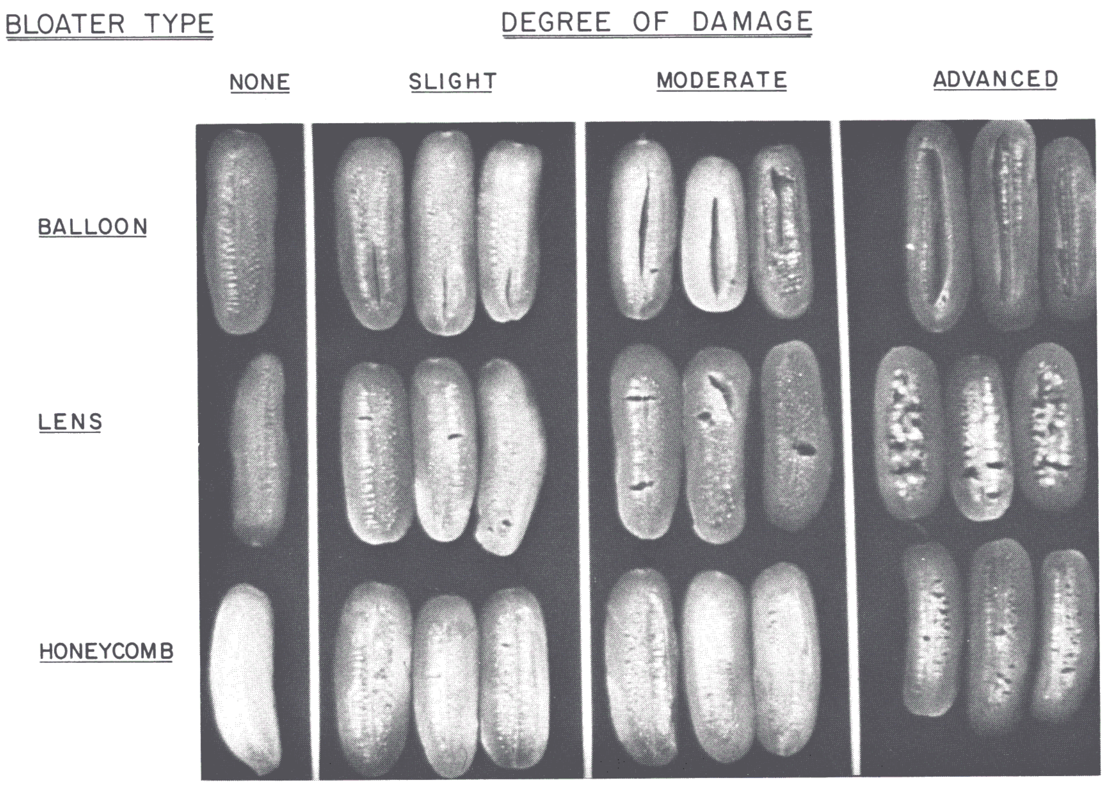

Fig. 5. Bloater evaluation chart. This chart has been proposed as a standard for evaluation of bloater damage (30). The degrees and percentages of balloon, lens, and honeycomb bloating can be converted to a "bloater index" for statistical analysis or other uses (25). Brine stock on the left represent what can be achieved with an effective purging operation. Proceeding to the right, one can visualize the degrees of damage that can occur with excessive levels of CO_2. In extreme cases, the entire seed area is pressed against the outer skin and flesh, leaving a completely hollow seed area.

CRITICAL LEVEL OF CO_2 FOR BLOATER DAMAGE

Because purging introduces an additional expense in brining, briners naturally are concerned with the *critical concentration* of CO_2, that is, the maximum level of CO_2 that can be tolerated without causing serious bloater damage. We originally indicated that the CO_2 concentration should be kept below 20 mg/100 ml brine (23). This level was a conservative guess, one that will very likely prevent bloater damage. More recent information indicates that higher levels of CO_2 can be tolerated, depending on the brine temperature (Table 3).

TABLE 3.

Approximate maximum brine concentrations of CO_2 for prevention of bloater damage of brined cucumbers at various temperatures.[a]

		CO_2 concentrations, mg/100 ml brine	
Brine temperature		100% Saturation[b]	Maximum level for prevention of bloaters
°F	°C		
Low temperature brines (50% CO_2 saturation)			
60	15.6	142	71
65	18.3	130	65
70	21.1	120	60
High temperature brines (30% CO_2 saturation)			
75	23.9	112	34
80	26.7	104	31
85	29.4	96	29
90	32.2	90	27

[a]These levels are *guidelines only* and should not be considered absolute. Variations among cucumbers and environmental factors will influence the maximum level of CO_2 that can be tolerated, but serious damage should not occur below these levels.

[b]CO_2 solubilities are for 25° salometer brine.

The problem is very complex, however, and will require further study and experience to fully understand. Some of the factors that influence this critical level include:

1. *Properties of the cucumbers brined.* Cucumber size, cultivar (variety), and physiological state (as affected by season and post-harvest storage conditions, etc.) all probably contribute to susceptibility of the fruit to bloater damage.

2. *Geometry of the brining tank.* The critical level of CO_2 for bloater damage varies with depth within the brining tank. If brines are not purged or circulated in any way, the CO_2 concentration reaches higher levels at the bottom of the tank, and bloater damage is thus greater for cucumbers brined at greater depths (21). On the other hand, if brines are purged or circulated, the CO_2 concentration is more uniform throughout the brine, and cucumbers are more likely to bloat near the top than at the bottom of the tank at a given CO_2 concentration (25). This is true because of a complex relationship among effects of hydrostatic pressure, buoyancy pressure, and CO_2 concentration in the brine tank. Hydrostatic pressure resists gas expansion and, therefore, bloater formation at greater depths. In contrast, buoyancy pressures cause more physical damage to cucumbers near the top than at the bottom of the tank, which causes the cucumbers to bloat more readily.

3. *Salt concentration and brine temperatures.* Salt concentration and brine temperatures are the two primary factors that influence solubility of CO_2 in brines. At constant concentration of salt in the brine, CO_2 solubility decreases as temperature increases (Fig. 6). At constant temperature, CO_2 solubility decreases

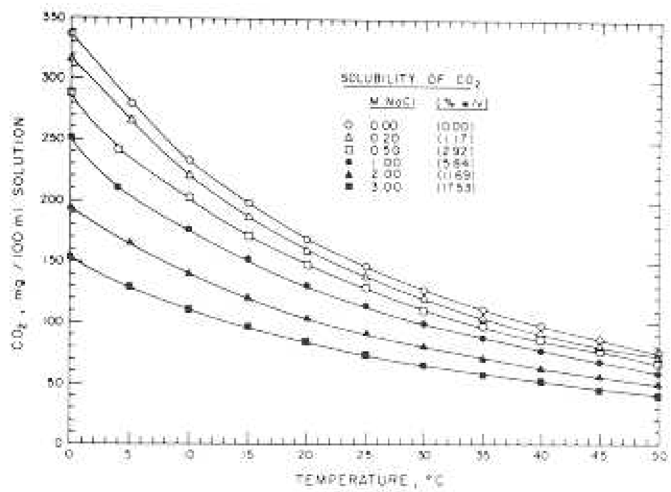

Fig. 6. Solubility of CO_2 in brines from 0 to 50 °C (32 to 122 °F). From Fleming et al. (24).

as salt concentration increases (Fig. 7).

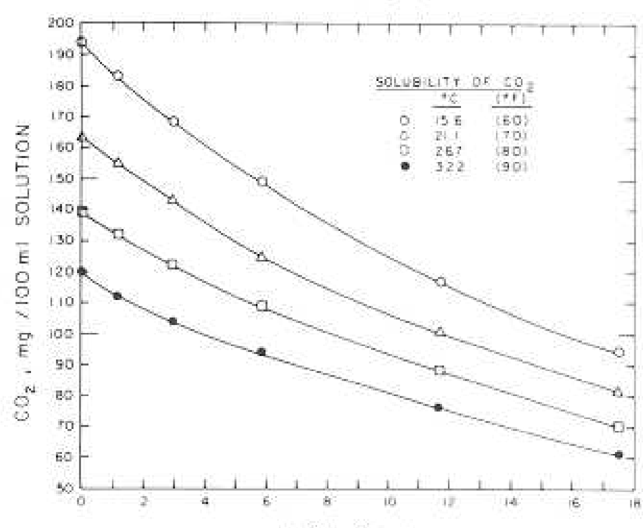

Fig. 7. Solubility of CO_2 in brines from 0 to 18% NaCl.

Bloater damage is not as severe in cucumbers brined at low as compared to high temperatures, even though CO_2 concentration may be the same, apparently because CO_2 solubility is higher at lower brine temperatures

(26). It would certainly simplify matters if we could give a critical level of CO_2 that would hold for all temperatures. Too many factors are involved to give one such concentration. We found, however, that % CO_2 saturation in the brine,

where % CO_2 saturation =

$$\frac{\text{CO}_2\text{ concentration in the brine}}{\text{maximum CO}_2\text{ that the brine can hold at that temperature and pressure}} \times 100$$

relates more closely to bloater damage than does CO_2 concentration (mg/100 ml brine) (26).

We can provide approximate guidelines for critical levels of CO_2 when cucumbers are brined at about 25° salometer and 60 to 90°F (Table 3). We suggest that brines be held below 30% CO_2 saturation at temperatures of 75°F and above, and below 50% saturation at temperatures below 75°F. These guidelines apply only to continuously-purged brines and allow a small safety margin. We cannot give one % CO_2 saturation that would be the critical level at all brine temperatures because higher brine temperatures apparently foster greater bloater formation in ways other than by the reduction in CO_2 solubility (26).

MEASUREMENT OF DISSOLVED CO_2

If a purging operation is to be most efficient, CO_2 in the brine must be accurately measured. Brines must be purged sufficiently to maintain CO_2 below the critical level, but excessive purging is wasteful.

First, a representative sample of brine must be obtained, such as by the siphoning method which we have described (18). We suggest that the brine sample be stored in a vacuum-type test tube containing sodium hydroxide solution prior to analysis (18). The sample can be analyzed by a highly accurate time-consuming procedure (17), but the Harleco method (18) is rapid, reasonably accurate and is recommended for routine analysis of commercial brines.

Faulty data will result from improper sampling and analytical techniques. In sampling, the brine must be drawn into the sampling syringe (the plastic disposable type is satisfactory for purged brines) slowly, or CO_2 will be removed from the solution, especially if brines are nearly saturated or super-saturated with CO_2. Such high concentrations should not occur with purged but do occur in unpurged brines. For high CO_2 concentrations, we recommend the use of a gas-tight syringe assembly (e.g. Hamilton Company, Whittier, CA) that can be closed after withdrawing the brine sample from the sampling port and before removing the needle from the port. The sample is then injected into the sodium hydroxide-containing vacuum tube, and the CO_2 is thereby trapped. Atmospheric contamination of the sodium hydroxide used to trap CO_2 in the tubes should be minimized, since sodium hydroxide readily absorbs CO_2.

The Harleco method is a gasometric method of analysis, and as such, is influenced by those factors that influence gas volume and pressure. The samples should be equilibrated to the same temperature as that of the standard solution to which it is related. Handling of the glass assay syringe should be minimized to avoid influencing the syringe temperature.

We have heard people say that they prefer to do the Harleco analysis at tankside. This is acceptable, provided the analyst has some means of maintaining a uniform temperature during assay of the sample and the control solutions upon which the calculations are based. For routine tests, we believe more reliable results will be obtained if the samples are taken in vacuum tubes and then transported to the quality control laboratory where the temperature is uniform and the analyses can be performed under more comfortable conditions.

We also have heard people say that they see no need for the syringe or the vacuum tube. They "just take the brine sample in a jar and cap it up," or they "just run some brine right into a test tube." Although the CO_2 in the jar or tube can be measured accurately, it may not even closely represent the CO_2 concentration in the brine tank, for CO_2 is highly volatile and easily lost from brine samples. It is more important to take the time and expense to obtain a few accurate analyses than to be misled with a raft of meaningless data. The accuracy of innovations in brine sampling or assay should be confirmed before they are released to quality control personnel for routine use.

The CO_2 electrode may eventually be an important means of measuring CO_2 in brines. The method, used extensively in clinical laboratories, involves highly sophisticated and expensive equipment. Some modifications from the measurement of CO_2 in blood are needed to make the procedure reliable for cucumber brines. High salt concentration and acidity and low pH of cucumber brines must be considered in adapting this method for use with brines. Future developments with this method of assay can be expected.

PURGING DEVICES

Purging devices are devices that release small bubbles of gas into the brine for the purpose of removing CO_2. Efficiency of CO_2 removal from brines is inversely related to bubble size. Smaller bubbles are more efficient, to a point. Such devices, called *spargers* in other industries, are used to introduce oxygen into a solution for the productions of antibiotics and vitamins by aerobic microorganisms; to introduce oxygen into waste treatment lagoons to stimulate oxidation of organic materials by aerobic microorganisms; and to remove oxygen by introducing N_2 into foods that may undergo undesirable flavor changes in the presence of oxygen or CO_2. Numerous devices have been used to purge CO_2 from brines. Several companies have designed and built their own equipment, and take considerable pride in their innovations. Such responses should be encouraged by management because this is another source for new developments or gadgets to improve efficiency of CO_2 removal. Before releasing new ideas or equipment for routine use in the brine yard, however, they should be evaluated for efficiency as well as for possible deleterious effects on the brined product. The various materials that have been used to fabricate spargers for cucumber brines are shown in Figure 8.

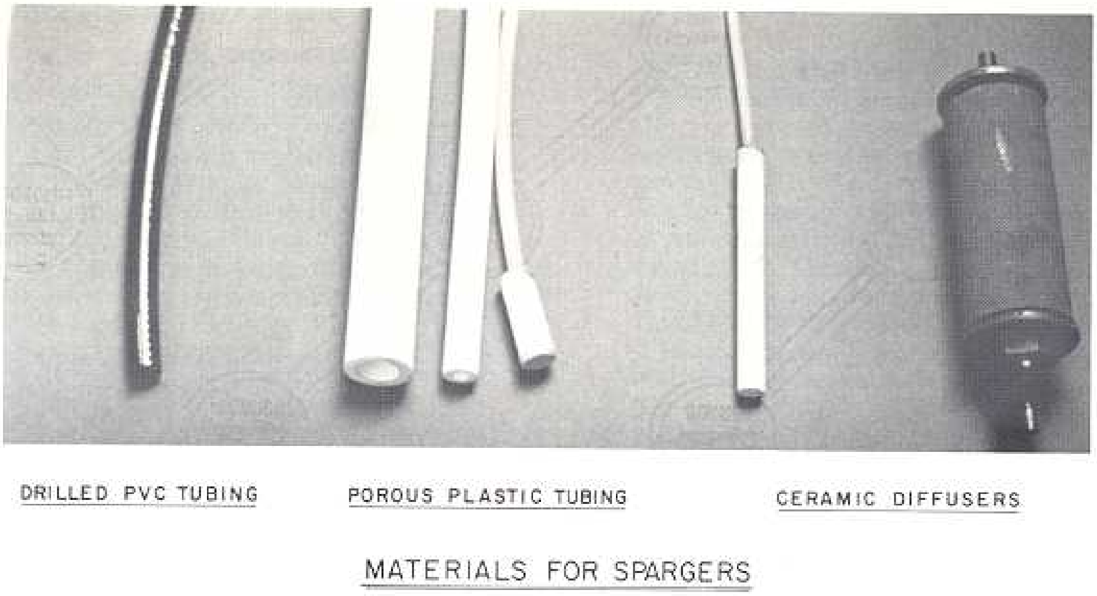

Fig. 8. Materials that have been used to fabricate spargers. From left: PVC tubing (Carlon Products, Wilton, CT), porous plastic tubing (Porex Materials Corp., Fairburn, GA), ceramic diffusers (left, Coors Porcelain Co., Golden, CO; right, Ferro Corp., East Rochester, NY).

The first experimental purging device was a fritted-glass gas disperson tube placed in a 1-gal jar of brined cucumbers (20). The first such device used in a commercial tank was simply a spiral of 3/4-inch diameter flexible plastic pipe drilled with 14, 1/64-inch diameter holes, secured to the bottom of the tank (23). Pipe diameters down to 1/4-inch have been successfully used. The pipe may be laid in a spiral or in concentric rings on the tank bottom (Fig. 9). In this type of bottom purger

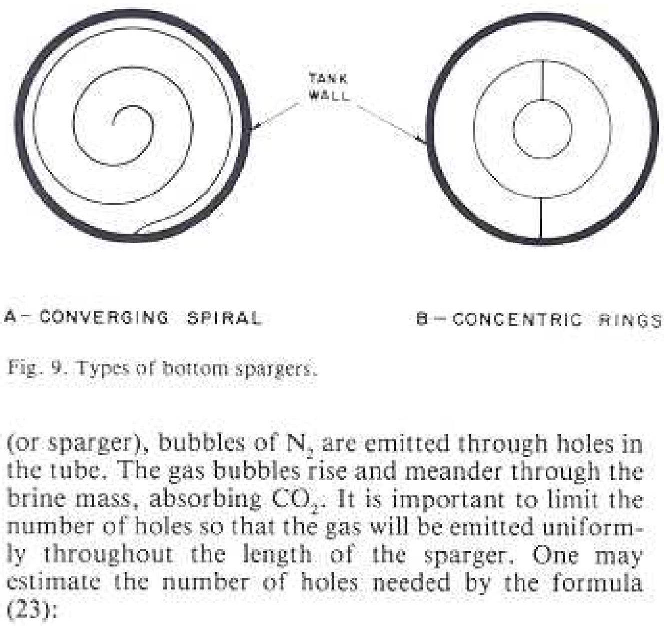

Fig. 9. Types of bottom spargers.

(or sparger), bubbles of N_2 are emitted through holes in the tube. The gas bubbles rise and meander through the brine mass, absorbing CO_2. It is important to limit the number of holes so that the gas will be emitted uniformly throughout the length of the sparger. One may estimate the number of holes needed by the formula (23):

Number of holes = (diameter of tank in feet)^2/10.

Roughly, this amounts to one hole every 2 ft of pipe. The holes should be drilled about 30° down from the top center of the pipe as it is placed in the floor of the tank.

Scientists at Michigan State University developed a side-arm purger that has the additional advantage of circulating the brine through the side arm (28). Purging gas is introduced into the brine through a porous ceramic diffuser (Kellundite diffuser, Ferro Corporation, East Rochester, NY) placed inside a 4-inch diameter PVC pipe. The pipe is mounted inside the tank and extends from the bottom of the tank to just above the headboards. Holes are drilled in the PVC pipe, near the bottom of the tank to allow brine to enter. A gas diffuser is mounted inside and near the bottom of the PVC pipe. As gas is emitted from the diffuser, it forces brine up through the PVC pipe and out through an exit in the side-arm pipe just below the brine surface. Thus,the purging gas removes CO_2 and improves brine circulation. A similar system developed about the same time by LH. Hontz (Mount Olive Pickle Company, Fig. 5) follows the general principles of the purger described by the Michigan State workers, but a Porex (Porex Company, Fairburn, GA) plastic diffuser is used for introducing purging gas into the brine. Mr. Hontz (31) indicates that his idea stemmed partially from the fact that his company for years has used an air pump placed in the salt box of brine tanks to circulate the brine occasionally so as to keep the brine strength uniform through the tanks. The brine circulation feature of the side-arm purger has been particularly useful to briners who use the entire controlled fermentation process, for it allows the initial acid, the lactic acid bacteria culture, and buffer additives to be conveniently introduced into the tank and mixed.

PURGING GASES

Nitrogen, inert gas (combusted air), and air have been used to effectively remove CO_2 from brines. Certain other gases also would work, but these three are nontoxic and seem to be the most economical. Each of these gases is effective because its solubility in brine is lower than that of CO_2. The composition of these gases and their effects on brined cucumbers are summarized in Table 4.

TABLE 4.

Composition of gases used for purging CO_2 from cucumber brines and their effects on brined cucumbers.

Purging gas	Composition Gas	%	Effects on cucumbers
N_2	N_2	> 99.99	Delayed appearance of curing
	Other	< 0.01	
Inert gas	N_2	> 88.0	Delayed appearance of curing
	CO_2	11.4	
	Other	<1.0	
Air	N_2	78.08	More rapid appearance of curing
	O_2	20.95	Sporadic occurrence of: gray,
	CO_2	0.03	pink, or other off colors;
	Other	0.94	off flavors; softening

Nitrogen was used in initial commercial studies because it was not considered likely to harm the quality of the finished product in any way. In the 10 years of our experimentation with purging, we have found no evidence that N_2 has any adverse effect on quality of the cucumbers. However, the cucumbers do not attain the visual appearance of cure as rapidly as when they are not purged or when they are purged with air.

The scale of the purging operation will dictate the most economical means of purging and the forms in which N_2 or inert gas should be obtained. For one or two experimental brining tanks, compressed N_2 is the most practical and economical (Fig. 10). The cost of N_2 per unit volume in this type of container, however, is prohibitive for commercial application.

Fig. 10. Use of compressed N_2 for experimental purging of cucumber brines. The side arm is raised here to illustrate brine flow. Brine should exit the side arm at or below the brine surface as in Figure 4. Compliments of Mount Olive Pickle Company, Inc.

Liquid N_2 can be obtained economically for commercial purging purposes, stored in bulk tanks on the premises (Fig. 11), and gaseous N_2 can then be piped throughout the tank yard as needed. The tank is mounted on a concrete pad prepared at the briner's expense. It is very important to minimize leakage of N_2 throughout the piping system in order to minimize costs. Nitrogen usage is most efficient when it can be effectively used over a short period of time, for N_2 continually bleeds from the bulk storage tank as a means of controlling tank pressure. The cost of liquid N_2 varies widely, and depends on volume usage and geographical location. We have heard of total purging costs using liquid N_2 ranging from 5 to 15 cents per bushel of brined cucumbers.

Fig. 11. Bulk tank for liquid N_2 storage. Compliments of Mount Olive Pickle Company, Inc.

For extensive purging, an inert gas generator should be considered. Mount Olive Pickle Company, Inc., has used a 1000 standard cubic feet per hour (SCFH) generator successfully for several years (Fig. 12). The generator should be protected from the harsh salt-acid

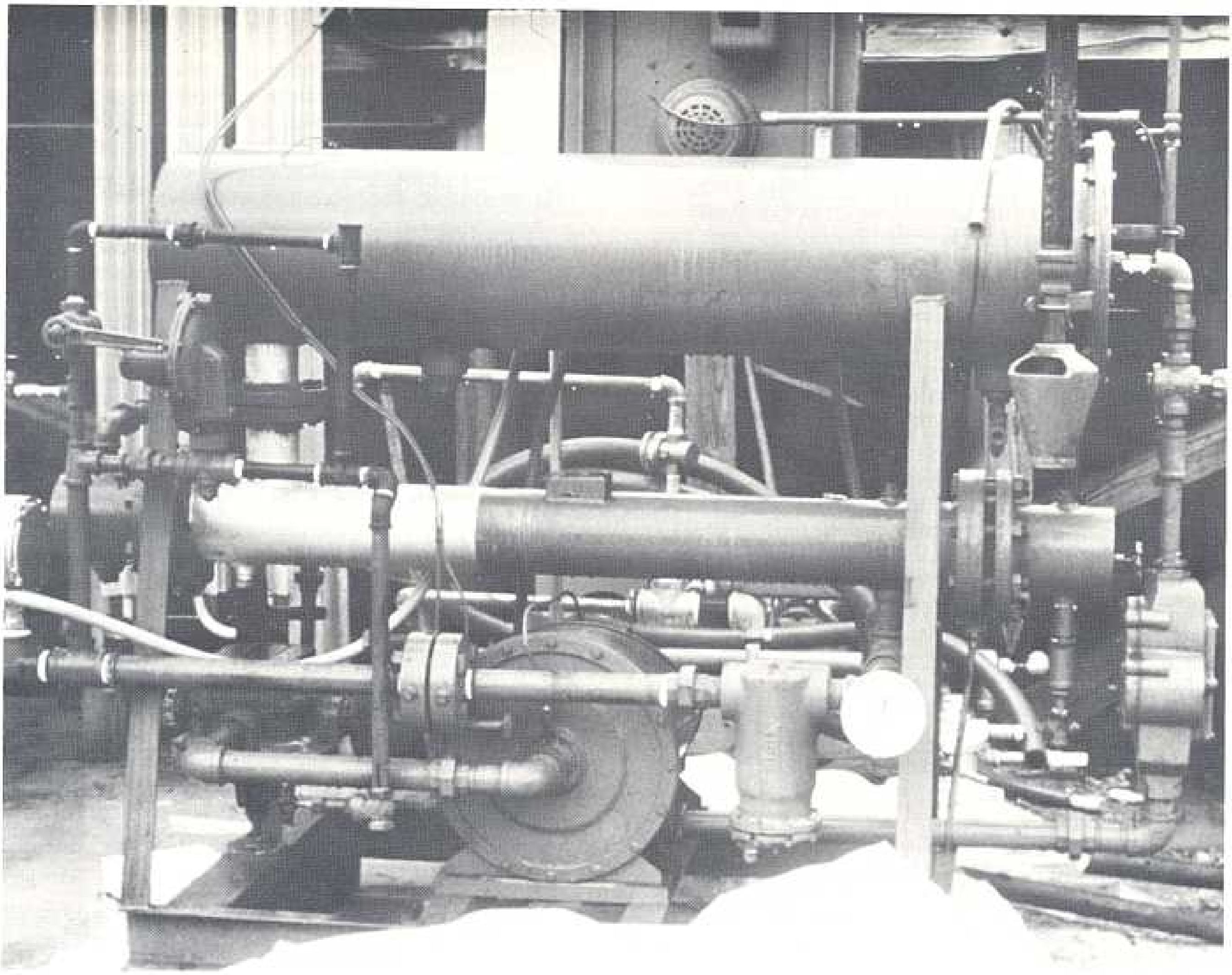

Fig. 12. Inert gas generator. Compliments of Mount Olive Pickle Company, Inc.

environment of a brining yard by a shed (Fig. 13) or other protective shelter. Surge tanks are needed to hold sufficient gas to insure continued purging (Fig. 13). Natural or bottled petroleum gas is required to operate the generator. An activated carbon filter may be used to remove traces of hydrocarbons generated, although we have no evidence to indicate that any adverse effects upon product flavor warrant such a filter.

Fig. 13. Storage shed for inert gas generator and surge tanks for inert gas. Compliments of Mount Olive Pickle Company, Inc.

Inert gas is generated by combustion of the oxygen in air and is converted to a mixture of CO_2, N_2, and traces of other gases (Table 4). The small amount of CO_2 in this gas slightly reduces the efficiency of this gas in removing CO_2 from brines, but inert gas can be less costly overall when the purging operation requires sufficient gas to justify its use.

Air will effectively remove CO_2 from brines and will result in reduced bloater damage. However, oxygen in the air can cause several problems, which I will discuss in a later section.

Briners who wish to seriously commit their companies to purging should analyze the cost of various options for purging. Major equipment and supply needs for these options are summarized in Table 5. Additional ex-

TABLE 5.

Primary items needed for purging brines with N_2, inert gas, or air.[a]

Items needed	Compressed N_2	Liquid N_2	Inert gas	Air
Gas cylinders (supplied by gas dealer)	+	–	–	–
Liquid storage tank (rented from gas dealer)	–	+	–	–
Concrete pad for tank	–	+	–	–
Natural or compressed petroleum-gas	–	–	+	–
Air compressor	–	–	–	+
Inert gas generator & compressor	–	–	+	–
Cooling water	–	–	+	–
Electricity	–	–	+	–
Charcoal filter (optional)	–	–	+	–
Storage shed	–	–	+	+
Surge tank	–	–	+	–
Diffuser (ceramic or plastic type)	+	+	+	+
Flowmeters (to read in SCFH)	+	+	+	+
Piping to each tank (with leak-proof connectors and able to withstand up to 15 psi)	+	+	+	+

[a]Items needed are indicated by a "+;" those not needed by a "–."

penses for brine analyses should be considered in the cost analysis, along with the economic advantages of purging.

RATES AND LENGTHS OF TIME FOR PURGING WITH N_2 OR INERT GAS

Because N_2 and inert gas purging introduce an additional expense in brining, it is important to limit their use in maintaining the brine CO_2 below the critical level. The only way to insure minimum usage of purging gas for a given purging device is to monitor dissolved CO_2 so that purging gas is added only as needed. Generally, CO_2 can be kept below the critical level (Table 3) by purging until the reducing sugar (fermentable sugar) in the brine is less than 0.05%, and the increase in titratable acidity is less than 0.05% on 2 consecutive days, and then discontinued.

Suggested rates and schedules for purging have been published (23, 28). Etchells et al. (23) suggested a continuous purging rate of 20 to 25 SCFH of N_2 for 8 to 12 days with controlled fermentation and a bottom purger in a 5,000-gal tank of fermenting cucumbers. Costilow et al. (28) recommended a continuous purging rate of 20 SCFH for 15 days with natural fermentation and a side-arm purger in an 8 ft deep x 14 ft diameter tank (about 9,000 gal). These guidelines are useful but should not be considered absolute. Experience has shown that it may be desirable to purge at a relatively high rate (30 to 40 SCFH for 10,000-gal tanks, using a side-arm purger) during the first few days after brining when large amounts of CO_2, from the cucumbers and the most active stage of fermentation, must be removed (Fig. 2). Then, the purging rate can be reduced (10 SCFH, for example). Some briners use continuous purging until the most active fermentation stage is over (until 0.8% acid is produced, for example), and then use intermittent purging as required to maintain CO_2 below the critical level. Intermittent purging is risky, however.

If the critical level of CO_2 is exceeded for even a few hours, as is more likely with intermittent than with continuous purging, bloater damage can occur (26). For N_2 or inert gas purging, we believe that continuous purging is preferable, especially during the early stages of brining. Continuous purging is theoretically more efficient in removing CO_2, if rates are properly controlled, because CO_2 is distributed between the brine and the cucumber tissue, and only the CO_2 in the brine surrounding the cucumbers is exposed to the purging gas. Diffusion of CO_2 out of the cucumbers into the brine is more of a limiting factor in intermittent purging.

Obviously, a precise purging schedule and rate cannot be given for the entire country or even for one brining station, if maximum economy of gas usage is to be realized. The brine yard superintendant and quality control personnel must understand the objective of purging and be able to accurately analyze for CO_2, acidity, salt, etc., in order to make wise decisions for their purging operation. I realize that many companies do not have the technical personnel to do all the analytical work suggested and may decide that it is economical for them to purge more than actually required to assure successful bloater control.

PURGING NATURAL VERSUS CONTROLLED FERMENTATIONS

Costilow and co-workers (28) reported success in reducing bloater damage by purging natural fermentations. Our laboratory studies have shown that purging does not reduce bloater damage in natural fermentations as consistently as it does in controlled fermentations, even though CO_2 is removed from the brine surrounding the cucumbers (24). On the other hand, we have observed effective control of bloater damage in purged natural fermentations in commercial tanks. Possible reasons for this inconsistency are being studied. Acetic acid (or vinegar) added initially to the brine may be at least partly responsible for the more consistent reduction in bloater damage by purging controlled fermentations. Carbon dioxide is purged more rapidly from brines at low pH (24). Costilow et al. (28) added about 0.05% acetic acid (to pH 4.5) to their "natural" fermentations, which may have accounted for their success.

In general, the rate and length of fermentation are more predictable in controlled than in natural fermentations. At 75 to 85 °F brine temperature, the fermentation and need for continuous purging are finished within 7 to 10 days. The addition of a culture and acetate buffer in controlled fermentation insures a more rapid and complete fermentation. Although natural fermentations may proceed as rapidly as controlled fermentations in some instances, at other times, fermentable sugars may remain in natural fermentations for several weeks, necessitating extended monitoring and purging of the brines.

WHAT ABOUT AIR PURGING?

As mentioned earlier, purging brines with air will remove CO_2 and prevent bloater damage. We have been aware of this fact for over 8 years, but have not recommended air purging because of its potential problems. Air is being used by some briners, who report varying degrees of success. Although we also have had successful results with air in some instances, we still have reservations about the use of air for purging brines. The problems arise because of oxygen from the air, which dissolves in the brine. Oxygen solubility is determined primarily by salt concentration and temperature of the brine (Fig. 14).

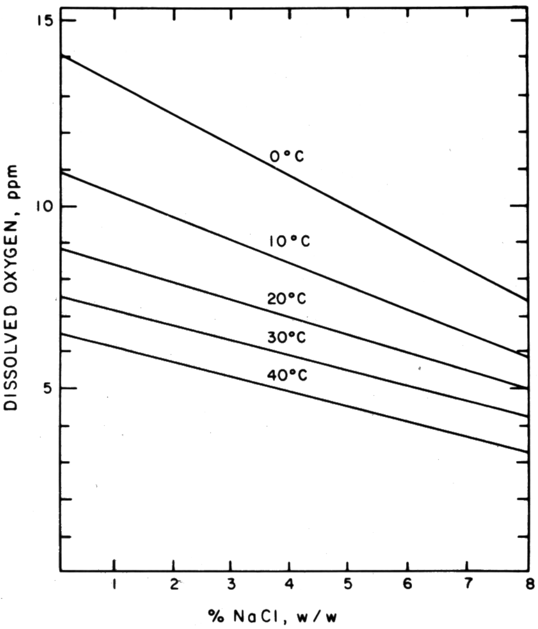

Fig. 14. Solubility of oxygen in brines. Calculated from Truesdale et al. (32) by Potts et al. (27.).

When aeration is discontinued in air-purged brines, the rate of oxygen depletion in the brine varies among tanks (Fig. 15) because of variations in types and

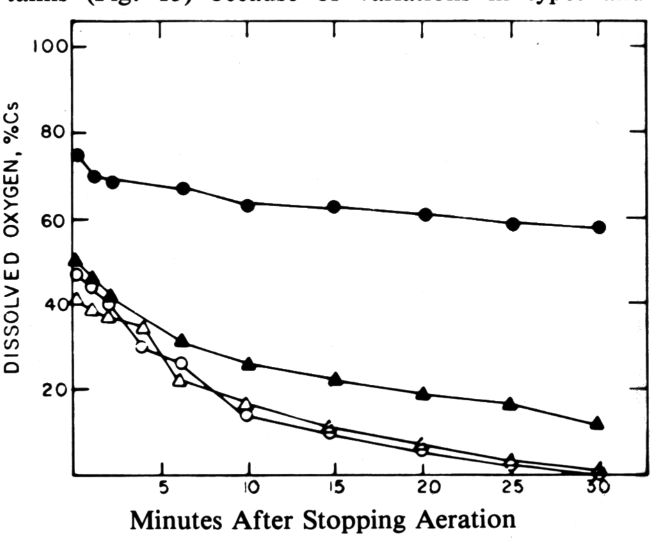

Fig. 15. Oxygen depletion in aerated, commercial cucumber fermentations. Two 10,000-gal. tanks were air purged with a side-arm purger. The air was cut off and the dissolved oxygen measured at times shown. Measurements for tank A were made on the 4th (▲) and 9th (△) days after brining. Measurements for tank B also were made on the 4th (●) and 9th (○) days after brining.

numbers of microorganisms active in the brine and other factors. Yeasts, especially the oxidative or film type, are encouraged to grow in air-purged brines and cause a rapid depletion of oxygen (26). In other words, oxygen stimulates growth of certain aerobic microbes which in turn cause a more rapid depletion of oxygen.

While a small increase in numbers of certain types of yeasts may not be important, excessive yeast growth can result in lower acid levels in the brine (27). Although there may actually be some advantage in reducing high levels of acid, which can result in acid-mediated softening of the cucumbers, acid should not be lowered below preservative levels (e.g. 0.6% as lactic acid).

Certain types of pectinase-producing fungi are stimulated by air purging, and these microbes can cause softening of the cucumbers (E.A. Potts and H.P. Fleming, unpublished). The problem seems to be less pronounced with controlled as compared to natural fermentations.

Discoloration (pink and grayish off colors) and undesirable flavors can occur in air-purged cucumbers (24). Undesirable flavors in pickle products from air-purged cucumbers may be caused by the growth in the brine of undesirable microorganisms such as film yeasts, and by chemical oxidation. Off flavors are particularly noticeable in pickle products such as genuine dills and hamburger dills. The delicate flavor of these products is easily ruined by undesirable flavors. Oxygen is notorious for causing oxidative flavors in many foods such as mayonnaise, coffee, potato chips, and certain juices; and great effort is made to exclude oxygen from these products.

There is one principle of microbiology that should especially be emphasized in relation to air purging. Microorganisms have an ability to adapt to an environment to some extent. Conversely, the environment has a great influence on the types of microorganisms that can survive and flourish. Up to now, oxygen has been largely excluded from fermenting cucumbers. It is conceivable that air purging could favor a gradual buildup in the growth of undesirable aerobic microorganisms in the brine yard. Such a trend could eventually cause serious problems in brining, as well as other operations in the processing of pickling cucumbers. In any case, we will continue to explore the possibilities and problems related to air purging.

Others also are studying the use of air for purging. Personal communications with R.N. Costilow (Michigan State University, East Lansing, MI) and R.G. Switzer (Western Food Products Company, Inc., La Junta, CO) indicate their cautious optimism concerning air purging. They indicate success with air purging of natural fermentations, but emphasize the need to acidify the cover brine (with 0.05% acetic acid to maintain an initial pH below 5; see reference no. 28 also) and to carefully control the air flow rate (not to exceed 20 SCFH).

There are too many factors involved for us to recommend the use of air for purging brines at the present time. Hopefully, briners who presently are air purging recognize the potential hazards and are monitoring their product so as to be alert to spoilage problems before they get out of hand. It would indeed be unfortunate for one to have success with air purging for a year or so, and to be lulled into a false sense of security. Spoilage may not occur with each tank of air-purged stock, or even with an entire year's stock; but problems may occur sporadically or tend to accumulate gradually with continued use of air purging. On the other hand, it is conceivable that a way will be found to safely use air.

QUESTIONS AND ANSWERS

Here are some questions, with answers, that we have been asked about purging of cucumber brines, which will serve to summarize some of the major points of this review and to bring out other points not previously covered.

1. **Question:** It sounds like you need a college degree to brine cucumbers nowadays. Is this realistic? I am not sure that we can afford this caliber of person.

   Response: Certainly the pickle industry is advancing technologically. This is good because we need to advance to maintain a competitive market for our product, not to mention increasing pressures from regulatory agencies. I think it is realistic to hire more technically qualified people. Alternatively, companies can encourage present employees to obtain additional training or employ college students in the summer months to handle certain technical operations.

2. **Question:** Is purging a panacea for bloater control in brined cucumbers?

   Response: Purging, if properly done, will go a long way toward solving the bloater problem. But it is not a panacea. Purging can help to retain the quality of cucumbers introduced into the brining tank, but it will not correct for physically damaged or genetically inferior cucumbers.

3. **Question:** What is the value of purging natural as compared to controlled fermentations?

   Response: As far as bloater control is concerned, more consistent results can be expected when the controlled fermentation procedure is used, but industry trials have indicated that the quality of naturally fermented cucumbers also can be greatly improved by N_2 purging. In the long run, however, controlled fermentation should be an objective of all briners who wish to remain in business. Improvements in the process and in brining tanks should make the entire process more attractive in the future. In the controlled process, we hope to eliminate excess salt and maintain a product of consistently high quality. Even if you are unable to use the entire process at this time, it would be wise to do some experimental tanks each year to keep your people alert to developments within this area.

4. **Question:** Do you recommend continuous or intermittent purging? For how long and at what rate should you purge?

   Response: We recommend continuous N_2 purging for the first few days of brining when the brines are fermenting very actively, or until the fermentable sugar in the brine is gone and there is no appreciable increase in acidity for 2 consecutive days. For controlled fermentations at 80 °F brine temperature, this is about 1 week. For natural fermentations, continuous purging may be needed for as little as 1 week, but can extend to several weeks, depending on how fast the natural microflora become established. A major problem with natural fermentations is the lack of sufficient buffering, which can result in residual sugar after the lactic acid bacteria stop growing. Conditions are right then for yeasts to take over and produce a lot of CO_2. The salt concentration and brine temperature also will determine the rate of fermentation and, therefore, the need for purging.

5. **Question:** Your figures in Table 3 indicate that higher levels of CO_2 can be tolerated at fermentation temperatures of 60 to 70 °F as compared to 75 to 90 °F. Wouldn't it be better to brine at these temperatures and reduce the amount of purging gas needed?

   Response: Not necessarily. In fact, we recommend that temperatures of 78 to 85 °F be used so that fermentation is completed as quickly as possible (23). Fermentation is slower at low temperatures than at high temperatures, necessitating purging for a longer period of time. In addition, the low temperatures favor growth of yeasts, which produce large amounts of CO_2 (Fig. 2), rather than the lactic acid bacteria.

6. **Question:** In using the side-arm purger, can the diffuser (sparger) be placed near the discharge end of the side arm rather than near the bottom of the tank?

   Response: Yes, but the efficiency of CO_2 removal from the brine would be reduced. The longer the N_2 gas bubbles are in contact with the brine, the more efficient CO_2 removal will be.

7. **Question:** Is there any appreciable difference in purging efficiency or in salt-stock quality for brines purged by the bottom versus the side-arm purger?

   Response: I know of no published information that gives conclusive evidence of the relative purging efficiencies of the two methods under commercial operations. Many briners prefer the side-arm method because of the ease of installation and removal of the purger, and its use as a brine circulator and means for conveniently adding cultures, buffer, and other ingredients. As for relative purging efficiency, this is a question that might best be answered from studies by qualified chemical engineers.

8. **Question:** Is there any way to tell if you are getting bloater damage during the critical period of fermentation without having to take cucumber samples from throughout the tank?

   Response: Some briners have a sampling port in the headboards for hand sampling that allows them to make quick estimations. Unfortunately, they only find out about the cucumbers at the top of the tank. Cucumbers at the top of the tank are frequently more bloated than those at the bottom because of physical damage brought on by buoyancy pressures at the top, and the fact that hydrostatic pressures cause less bloater damage lower in the tank. Sampling at different locations is the only way to ensure accuracy, and this is not very practical on a routine basis. Probably the simplest means of predicting bloater damage is by the degree of rise in the brine level of the tank. When bloating occurs, the brine level rises because of gas pockets being formed in the cucumbers. A tank that is overflowing with brine because of the fermentation (and not overfilling, rainwater, etc.) contains bloated cucumbers. Irreversible damage has already been done at this stage. You can, however, prevent further damage by increasing the purging rate.

9. **Question:** What are the dangers of purging with air?

Response: The potential problems are softening of brine stock, production of softening enzymes (which may not exert their softening influence until the cucumbers are desalted), poor color, poor flavor, excess utilization of fermentation acids by yeasts, and a build-up of undesirable aerobic microorganisms in the brine yard. The extent of these problems is presently unknown; further studies are needed to determine the extent of possible problems and/or benefits of air purging.

10. **Question:** What happens to the oxygen when you purge with air?

Response: Briefly, oxygen remains in the brine until the cucumber tissue or aerobic microorganisms use it. Oxygen stimulates the growth of aerobic microbes, which then consume the oxygen.

11. **Question:** How does one measure dissolved oxygen?

Response: The best way is with a dissolved oxygen electrode and meter. Several commercial instruments are available. One must compensate, however, for the salt in the brine to avoid erroneous values. The Winkler (33, 34) method, used for many years to measure oxygen in streams, wastewaters, etc., is not very accurate with cucumber brines, probably because of the high levels of organic materials.

12. **Question:** What if I purge at a low flow rate to reduce the amount of oxygen that can get into the brine?

Response: The principles that govern the efficiency of CO_2 removal from brine by purging also apply to the incorporation of oxygen into the brine by air purging. Thus, you must introduce enough air into the brine in order to remove CO_2, and in the process, oxygen necessarily is incorporated into the brine.

13. **Question:** Would you expect any problem with air purging when the side-arm system is used? The brine is in contact with air for only a short time in this system.

Response: In side-arm purging, the brine in the side arm is exposed to a very high rate of air flow, although it is for a short time. The high oxygen level of brine within the side arm can cause aerobic microbes, some of which may produce softening enzymes, to grow on the inside walls of the side arm and on the diffuser. Slime formation, apparently due to growth of aerobic microbes, on the diffuser has been reported by some users of air purging.

14. **Question:** Are there more problems with air purging when a bottom purger is used, compared to a side-arm purger?

Response: Probably. When air is introduced through the bottom purger, air bubbles rise through the cucumber mass. Air bubbles can become entrapped among the cucumbers and under the headboards and be the site for extensive growth of cucumber softening and other types of aerobic microorganisms.

15. **Question:** If I choose to air purge, and am set up to measure oxygen, should I be concerned if the oxygen level in the brine is above a certain level?

Response: The answer to this question is not apparent. In fact, one might argue that a high level of oxygen is bad, or that a low level is bad. A high level of oxygen might be argued to cause oxidative changes in the cucumbers which could result in off flavors or color problems. A low level of oxygen would be indicative of a high level of aerobic microorganisms which use the oxygen, and hence the reason for the low oxygen level. Some aerobic microbes can cause such problems as production of softening enzymes or the utilization of acid to the detriment of adequate precaution for preservation (27).

16. **Question:** You said that N_2-purged cucumbers cured slower. Could this be a major drawback to rapid turnover of the brine stock?

Response: Nitrogen purging slows *appearance* of cure in brined cucumbers. Nitrogen purging has no effect on rate of cure as indicated by disappearance of all fermentable sugars. Some briners do not consider this slow appearance of cure a problem. Others solve the problem by using warm water in the desalting operation. The warm desalting water drives trapped gas from the tissue, and the brine stock then takes on a more cured appearance.

17. **Question:** You say that air purging can cause softening of cucumbers. Is there any problem that N_2 purging can cause?

Response: Other than the curing problem cited in the above question, I know of no problems with brine-stock quality that are related to N_2 purging. We have no evidence or reason to believe that N_2 purging can cause softening problems. Over-sized cucumbers are resulting in an increasingly greater problem with soft centers, and we still have the problem with mold enzymes that contaminate cucumbers at the time of brining that can cause softening, but these problems are not related to N_2 purging. Nitrogen purging does not encourage the growth of softening microorganisms as does air purging.

Nitrogen, if improperly used, can cause a personnel safety problem, however. People have died from suffocation in rooms or chambers where N_2 had replaced the breathing air. Personnel should be warned of this problem if they plan to use N_2 in ways other than recommended for purging.

18. **Question:** How important is it to monitor brines and keep records?

Response: Accurate analyses and records are extremely important for justifying the efforts of purging and brining and for problem solving and prevention. Good records will allow the briner to determine the source of a problem so that he can prevent its recurrence. A good format for record keeping (35) includes evaluations of the green stock (condition at brining, size, internal faults, etc.); brine chemistry (pH, % acid, % salt, % reducing sugar, CO_2, and pectinolytic enzyme activity); and brine-stock quality (bloater defects, color, odor, firmness readings, and appearance). In addition, it is advisable to monitor the quality of the green cucumbers that go into the brine tank (for size, disease, freedom from mold growth, etc.).

19. **Question:** Do you think that we can close the research book on preventing bloaters now that we have found the solution and concentrate on other problems?

Response: Some people may be thinking so, but we certainly don't. Although we are involved in many other studies, we believe that it is much too early to discontinue our studies on the problem of bloater damage. We have not fully satisfied ourselves on the mechanism of bloater formation, and we need to consider more efficient means of purging or alternatives to purging. We need to resolve the numerous questions that remain about air purging and examine the numerous factors that affect the critical level of CO_2 for bloater damage.

REFERENCES

1. Veldhuis, M.K. and Etchells, J.L. 1939. Gaseous products of cucumber pickle fermentations. Food Res. 4: 621-630.
2. Etchells, J.L. and Jones, I.D. 1943. Bacteriological changes in cucumber fermentation. Food Inds. 15: 54-56.
3. Jones, I.D. and Etchells, J.L. 1943. Physical and chemical changes in cucumber fermentation. Foods Inds. 15: 62-64.
4. Etchells, J.L. and Bell, T.A. 1950. Film yeasts on commercial cucumber brines. Food Technol. 4: 77-83.
5. Etchells, J.L. and Bell, T.A. 1950. Classification of yeasts from the fermentation of commercially brined cucumbers. Farlowia 4: 87-112.
6. Etchells, J.L., Costilow, R.N. and Bell, T.A. 1952. Identification of yeasts from commercial cucumber fermentations in northern brining areas. Farlowia 4: 249-264.
7. Etchells, J.L., Bell, T.A. and Jones, I.D. 1953. Morphology and pigmentation of certain yeasts from brines and the cucumber plant. Farlowia 4: 265-304.
8. Phillips, G.F. and Mundt, J.O. 1950. Sorbic acid as inhibitor of scum yeast in cucumber fermentations. J. Food Technol. 4: 291-293.
9. Costilow, R.N., Ferguson, W.E. and Ray, S. 1955. Sorbic acid as a selective agent in cucumber fermentations. I. Effect of sorbic acid on microorganisms associated with cucumber fermentations. Appl. Microbiol. 3: 341-345.
10. Costilow, R.N., Coughlin, F.M., Robbins, E.K., and Hsu, W.T. 1957. Sorbic acid as a selective agent in cucumber fermentations. II. Effect of sorbic acid on the yeast and lactic acid fermentations in brined cucumbers. Appl. Microbiol. 5: 373-379.
11. Costilow, R.N. 1957. Sorbic acid as a selective agent for cucumber fermentations. III. Evaluation of salt stock from sorbic acid treated cucumber fermentations. Food Technol. 11: 591-595.
12. Bell, T.A., Etchells, J.L. and Borg, A.F. 1959. The influence of sorbic acid on the growth of certain species of bacteria, yeasts and filamentous fungi, J. Bacteriol. 77: 573-580.
13. Etchels, J.L., Borg, A.F. and Bell, T.A, 1961. Influence of sorbic acid on populations and species of yeasts occurring in cucumber fermentations. Appl. Microbiol. 9: 139-144.
14. 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: 1029-1035.
15. Etchells, J.L., Costilow, R.N., Anderson, T.E., and Bell, T.A. 1964. Pure culture fermentation of brined cucumbers. Appl. Microbiol. 12: 523-535.
16. *Official Methods of Analysis.* 1970. 11th ed., AOAC, Washington, D.C.
17. Fleming, H.P., Thompson, R.L. and Etchells, J.L. 1974. Determination of carbon dioxide in cucumber brines. J. AOAC 57: 130-133.
18. Fleming, H.P., Thompson, R.L. and Bell, T.A. 1974. Quick method for estimating CO_2 in cucumber brines. Advisory Statement prepared and distributed by Pickle Packers International, Inc., St. Charles, IL.
19. Fleming, H.P., Thompson, R.L., Etchells, J.L., Kelling, R.E., and Bell, T.A. 1973. Carbon dioxide production in the fermentation of brined cucumbers. J. Food Sci. 38: 504-506.
20. Fleming, H.P., Thompson, R.L., Etchells, J.L.,Kelling, R.E., and Bell, T.A. 1973. Bloater formation in brined cucumbers fermented by *Lactobacillus plantarum*. J. Food Sci. 38: 499-503.
21. Etchells, J.L., Fleming, H.P., Hontz, L.H., and Bell, T.A. 1975. 1975. Factors influencing bloater formation in brined cucumbers during controlled fermentation. J. Food Sci. 40: 569-575.
22. Fleming, H.P., Thompson, R.L., Kelling, R.E., Bell, T.A., and Etchells, J.L. 1972. Influence of carbon dioxide levels in the fermenting brine on bloater formation in cucumbers. Presented at 32nd Annual Meeting of Institute of Food Technologists, May 21-25.
23. 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: 4-14.
24. Felming, 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: 1304-1310.
25. 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: 1464-1470.
26. Fleming, H.P., Thompson, R.L. and Monroe, R.J. 1978. Susceptibility of pickling cucumbers to bloater damage by carbonation. J. Food Sci. 43: 892-896.
27. Potts, E.A. and Fleming, H.P. 1979. Changes in dissolved oxygen and microflora during fermentation of aerated, brined cucumbers. J. Food Sci. 44: 429-434.
28. Costilow, R.N., Bedford, C.L., Mingus, D., and Black, D. 1977. Purging of natural salt-stock pickle fermentations to reduce bloater damage. J. Food Sci. 42: 234-240.
29. Etchells, J.L., Bell, T.A., Fleming, H.P., and Thompson, R.L. 1976. Controlled bulk vegetable fermentation. Patent no. 3,932,674, January 13.
30. Etchells, J.L., Bell, T.A., Fleming, H.P., Kelling, R.E., and Thompson, R.L. 1974. Bloater chart. Prepared and distributed by Pickle Packers International, Inc., St. Charles, IL.
31. Hontz, L.H. Personal communication. Mount Olive Pickle Co., Inc., Mount Olive, NC.
32. Truesdale, G.A., Downing, A.L. and Lowden, G.F. 1955. The solubilities of oxygen in pure water and sea water. J. Appl. Chem. 5: 53.
33. *Standard Methods for the Examination of Water and Wastewater.* 1971. 11th ed., American Public Health Association, Washington, DC.
34. Winkler, L.W. 1888. The determination of dissolved oxygen in water. Dtsch. Chem. Ges. Ber. (Chem. Ber.) 21: 2843-2854.
35. Etchells, J.L. and Hontz, L.H. 1974. Quality control report for brining and salting cucumbers. Pickle Pak Sci. 4: 24-25.

ACKNOWLEDGMENTS

This paper was presented, in part, at the Western Regional Conference (Newport Beach, CA, April 6-7, 1978) and the Eastern Regional Conference (Point Clear, Al, April 13-14, 1978) of Pickle Packers International, Inc.

Paper no. *6114* of the journal series of the North Carolina Agricultural Research Service, Raleigh, NC.

The author thanks J.L. Etchells for his review and suggestions in the preparation of this manuscript, his influential guidance over the past 15 years, and his continued encouragement and support. He also thanks his co-workers, T.A. Bell and R.L. Thompson, who have participated in much of the research which is summarized in this review. D.H. Wallace, Atkins Pickle Company, Atkins, AR, and L.H. Hontz, Mount Olive Pickle Company, Inc., Mount Olive, NC, were most helpful in reviewing the manuscript, as they have been during development of the purging procedure over the years. A special note of thanks is due to W.R. Moore, Jr., Executive Vice President of Pickle Packers International, Inc., for encouraging the preparation of this review.

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

Pickle Pak **SCIENCE**

Published by

Pickle Packers International, Inc.

One Pickle and Pepper Plaza, Box 31
St. Charles, Ill. 60174 U.S.A.

DEC., 1979
VOL. VI — No. 1

"For Those Who THINK PICKLES"

CONTENTS