PROGRESS ON DEVELOPMENT OF AN ANAEROBIC TANK FOR BRINING OF CUCUMBERS*

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ABSTRACT

This paper summarizes 2 years of research on engineering and biological aspects of the project, "New Prototype Brining Tank for Pickling Cucumbers." The project is being sponsored by Pickle Packers International, Inc., and interested members of the pickle industry.

The paper describes 1,170-gal, dome-top fiberglass tanks with manways that are adapted for anaerobic storage of cucumbers. Accessory equipment for washing, loading, heading, purging, and unloading the cucumbers was adapted or developed and was demonstrated to function satisfactorily in the pilot system. Overall effectiveness of the pilot system and its components, and problems that must be studied further, are discussed.

Brush washing of the cucumbers resulted in removal of solid foreign material, and reduction in softening enzymes. Washing also greatly reduced the number of natural lactic acid bacteria. Thus, inoculation of washed cucumbers with a desirable culture of lactic acid bacteria, as was done in this study, may be necessary to assure a proper fermentation. The cucumbers, which were brined to equilibrate at 22° S NaCl and 0.2% $CaCl_2$, fermented normally in fresh and in recycled brine, with the fermentation rate being faster and final pH being higher in recycled brine as expected. The brine stock was of acceptable quality as to firmness and degree of bloater damage. Firmness of the brine-stock cucumbers decreased only 1 to 2 lbs during storage for 12 months at 22° S in the pilot tanks. The bloater index was 8 to 11 in the top one-third but was 1 or less in the bottom two-thirds of the tanks, which is consistent with previous findings in open-top tanks.

Development of a closed-top, anaerobic tank suitable for brining of cucumbers could be the focus for solving many environmental and regulatory problems of the pickle industry. Greatly reduced salt usage and disposal problems, and improved product quality and overall sanitation are obvious benefits that such a tank could offer. More importantly, such a tank could open the industry to anticipated new technology heretofore deemed impractical with open-top tanks. Although the results reported herein are not intended to imply final recommendations, substantial progress has been made. It is intended that this overview serve to inform companies and individuals within the pickle and allied industries as to our goals and progress. Assistance and cooperation is invited from those who can help assure the success of this project for the pickle industry.

INTRODUCTION

It is becoming increasingly apparent that the open-top brining tank currently in common use by the pickle industry is a source of serious environmental and regulatory concern. Growth of aerobic spoilage microorganisms on the brine surface, dilution by rainwater, and contamination by foreign material occur because the tank is open to the atmosphere. Extra salt is added as insurance against potential problems created by the open tank.

Perhaps of more economic significance, however, is the hindrance of open tanks to advanced technology. Controlled fermentation was introduced to the pickle industry over 10 years ago by Etchells et al. (1973). Purging of CO_2 from brines to prevent bloater damage was a part of that process, and has been widely adopted by the industry because of obvious economic benefits. Other parts of the process including washing of the cucumbers, buffering, and inoculation with a pure culture of lactic acid bacteria have not been widely adopted. The economic benefits were not strikingly obvious for these features of the process. Rainwater, foreign material, and surface growth of aerobic microorganisms were still a problem with open tanks, and negated some of the advantages of controlled fermentation.

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It is appropriate now, however, for serious introspection by the pickle industry concerning bulk storage of cucumbers and other vegetables. Fifty years ago, virtually all cucumbers for commercial use as pickles were brined. Today, only about 43% of the crop is brined. The remainder of the crop is preserved by pasteurization (43%) or refrigeration (14%). While these newer preservation methods undoubtedly have expanded the market for pickles, there are several inherent economic advantages in bulk, brine storage of vegetables. Bulk, brine storage of produce is a:

1) rapid, temporary means of preservation,
2) means of extending the processing season so as to distribute labor and equipment needs throughout the year,
3) low energy means of preservation, and
4) means for market hedging.

The industry does not have to suffer the loss of these advantages. Furthermore, it does not have to contend with environmental and sanitary problems long associated with brine storage. The industry could poise itself to take advantage of recent and anticipated new technology in brine storage of vegetables. We believe that the development or adaptation of a suitable anaerobic tank for bulk storage of cucumbers and other produce is a focal point for solving many regulatory problems of the pickle industry, and for opening the industry to significant technological advancement.

Numerous efforts have been made over the past 50 years to prevent problems associated with open tanks. The tanks are normally left outside so that sunlight will inhibit surface growth of aerobic microorganisms. If the tanks are sheltered, scum formation occurs and may result in softening spoilage and off-flavors. Ultraviolet light has been used to prevent scum formation on tanks sheltered or held indoors. But safety and expense of UV lights are a concern, and the brine remains exposed to foreign matter. Mineral oil has been used to prevent scum formation on sheltered tanks, but with only partial sucess; certain aerobic microorganisms grow under the oil layer (Etchells and Veldhuis, 1939). In addition, the oil creates handling and disposal problems. The sauerkraut industry has successfully used plastic sheets, overlaid with brine, to cover the kraut and drape over the tank edge (Pederson and Albury, 1969), thus creating a more anaerobic environment. This method has been shown to offer certain advantages with brined cucumbers (Finlay and Johnston, 1956). Punctures in the plastic, gas pockets created by fermentation gas and growth of aerobic microorganisms between the tank wall and the plastic are potential problems with the plastic overlay procedure. The "Payne" post-fermentation tank cover was an adaptation of the plastic overlay and was tested by the pickle industry over 20 years ago. The cover was designed by Dr. J. L. Etchells and Mr. W. H. Payne, National Textile Research, Inc., Raleigh, NC, (unpublished) in cooperation with the industry. A nonporous, vinyl-coated, nylon fabric was secured above the headboards of wooden tanks. The wooden staves of the tank were routed for securing of the fabric into the tank wall by means of plastic tubing formed into a hoop and nailed to the inside of the tank wall. Many companies tested the covers, but they were never accepted on a commercial scale.

The olive industry in this country and in Spain is now using anaerobic or nearly anaerobic tanks made of fiberglass or polyethylene for bulk storage of olives (Vaughn, 1975). These tanks, of various configurations, have only small manways for introducing and removing the product. Some of the tanks are installed underground in southern California to prevent softening of the olives due to high temperatures in above-ground tanks (Fleming, 1982).

Project objectives

Overall objectives of the present work are:

1. to design and develop a pilot-scale, closed top, anaerobic, brining tank for pickling cucumbers that will serve as a research model to test recent and anticipated technological advancements before they are introduced into full-scale commercial use, and
2. to design, develop, and evaluate accessory equipment for the pilot-scale tank as needed to integrate the new brining tank into a proposed overall handling system for commercial use.

The project, entitled "New Prototype Brining Tank for Pickling Cucumbers," is scheduled for 5 years, beginning in 1982.

A cooperative effort

The Board of Directors of Pickle Packers International, Inc., at its January 1982 meeting, heard the above justification and objectives. An individual and several companies pledged financial support for the project. The Board of Directors agreed that the association would underwrite the difference between what is donated by individual companies and the projected cost to support the 5-year effort. The project involves a cooperative effort among the pickle industry, allied industries, North Carolina State University, and the United States Department of Agriculture (Fig. 1). Knowledge and cooperation of commercial firms and individuals is actively sought. The pilot operation is located at Mount Olive Pickle Company, Mount Olive, NC. Information gained from the project is available to the entire pickle industry.

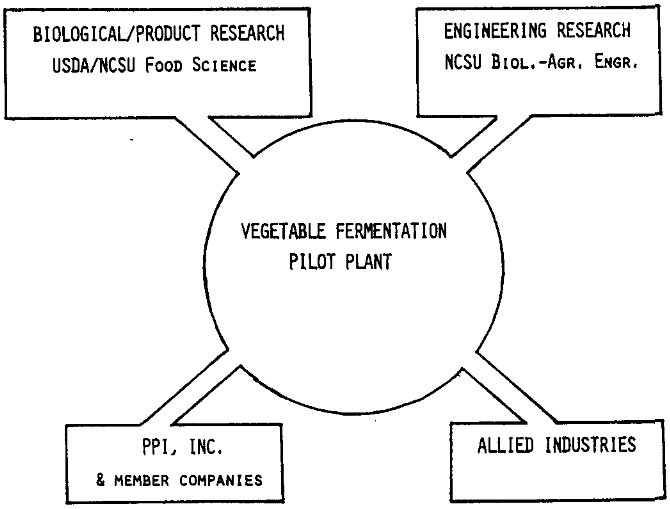


Fig. 1. Cooperators involved in development of an anaerobic tanking system for the pickle industry.

Objective of this report

The objective of this report is to summarize progress on the tank project to date. It is emphasized that all parameters have not been adequately researched to provide recommendations for tank design or for an overall tanking system that will be required with a closed tank. The pickle industry has shown such considerable interest in the project, however, as to warrant disclosure of the current status of the project. Furthermore, we have found tank manufacturers and other industries to be very helpful after they understand the requirements of the pickle industry and the potential for anaerobic tanks. Hopefully, this report will serve as a means for improving communications on the project and for enlisting cooperation of individuals and companies needed to insure success of the project.

MATERIALS AND METHODS

Tanks

Two cylindrical fiberglass tanks, model CM-CFV-5, manufactured by Warner Fiberglass Products, 60 inches diameter and 96 inches high with an 8-inch domed top equipped with a standard, 24-inch diameter flanged manhole opening in its center, were selected as fermentation tanks. The above tank height was chosen to simulate typical industry conditions since brine depth is the critical factor that influences product quality (Fleming et al., 1977); the relatively small diameter was selected to keep the volume of cucumbers required to fill the tanks at a reasonable level for experimental work. The flat bottom, 1,170 gal capacity tanks each were equipped with a 4-inch side-bottom flange access port and installed on a concrete pad at the Mount Olive Pickle Company manufacturing facilities, Mount Olive, NC, in 1981. A platform working area, 16 × 18 ft, was constructed around the tanks with the deck approximately 50 inches below the tank tops. Figure 2 shows the overall installation with several components of accessory equipment that are referred to below.

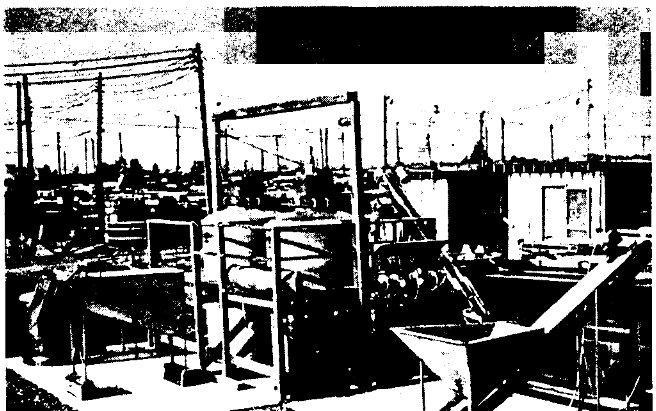


Fig. 2. Overall view of pilot tank installation showing dry hopper receiving station (right foreground), washer and elevator to tanks, tanks (shown with tank caps in place), and brine-stock separator unit for unloading (left foreground). Note the conventional open-top tanks in the background.

Washing/loading system

A materials handling and washing system (schematically shown in Fig. 3) for loading cucumbers into the tanks was assembled from existing equipment. Size no. 3 cucumbers (hand-picked, free of disease and serious mechanical injury) were dumped from 20 bu field boxes into a dry hopper/conveyor which delivered them to an Osborn U-Brush Washer, model 810-273, equipped with an oscillating spray nozzle manifold, donated to the project by Charles F. Cates Pickle Company, Inc. The water spray in the washer was recycled from a collector tub underneath the washer. The discharge from the washer was elevated by a flat-belt, flighted conveyor to a height roughly corresponding to the tank tops. The cucumbers received a final rinse with clean water from spray nozzles mounted on the conveyor. Final delivery to the tanks was made by a semi-portable, flat-belt conveyor that could be easily-positioned to discharge into either tank. The materials handling system for loading the tanks was assembled and installed by personnel of the Mount Olive Pickle Company, Inc. The tanks were approximately half-filled with water to cushion the cucumbers from their fall during tank loading. A total of 5,680 lbs of cucumbers was required to fill each tank, which occupied 60% of the volume of the tank (i.e., a pack-out ratio, cucumbers:brine, of 60:40, assuming a cucumber density of 0.97).

Efficacy of cucumber washing

Four replicates of six cucumbers (total of 700-900 g) each were randomly picked from the conveyor before entrance into the washer, and four similar replicates were taken from the conveyor after the washer. Each weighed batch of six cucumbers was placed in a gallon jar containing 1 liter of sterile 0.85% saline and shaken vigorously 20 times in each of three ways: 1) sideways, 2) up and down, and 3) in a circular rolling motion. A 100-ml sample of each washing was filtered through preweighed, Whatman no. 1 filter paper and dried in an oven (74 °C) overnight and then reweighed. Weight of foreign material (grit and other loosely adhering material on the cucumber surface) contained on the tared filter was thus obtained. Total foreign material removed was calculated as mg/g cucumber.

Microbiological determinations of the wash water from the gallon jars were made using standard methods for serial dilution and plating. Plating media were: 1) Standard Methods Agar (Difco Laboratories, Inc., Detroit, MI) for total aerobes, 2) violet red bile agar (BBL Labs., Cockeysville, MD) with 1% glucose for total *Enterobacteriaceae* (Mossel et al., 1962), 3) MRS AGAR (BBL Labs.) with 0.02% sodium azide for total lactic acid bacteria (Daeschel et al., 1981), and 4) dextrose agar (Difco Labs.) acidified with 5 ml of 10% sterile tartaric acid per 100 ml just before plating for total yeasts and molds.

Softening enzyme activity in the wash water was determined by the viscometric method of Bell et al. (1955). Softening activity was determined with pectate solution buffered at pH 5.0 with 0.02 M sodium citrate (estimate of low pH enzymes normally associated with molds) and at pH 9.0 with 0.02 M sodium borate (estimate of high pH enzymes normally associated with bacteria).

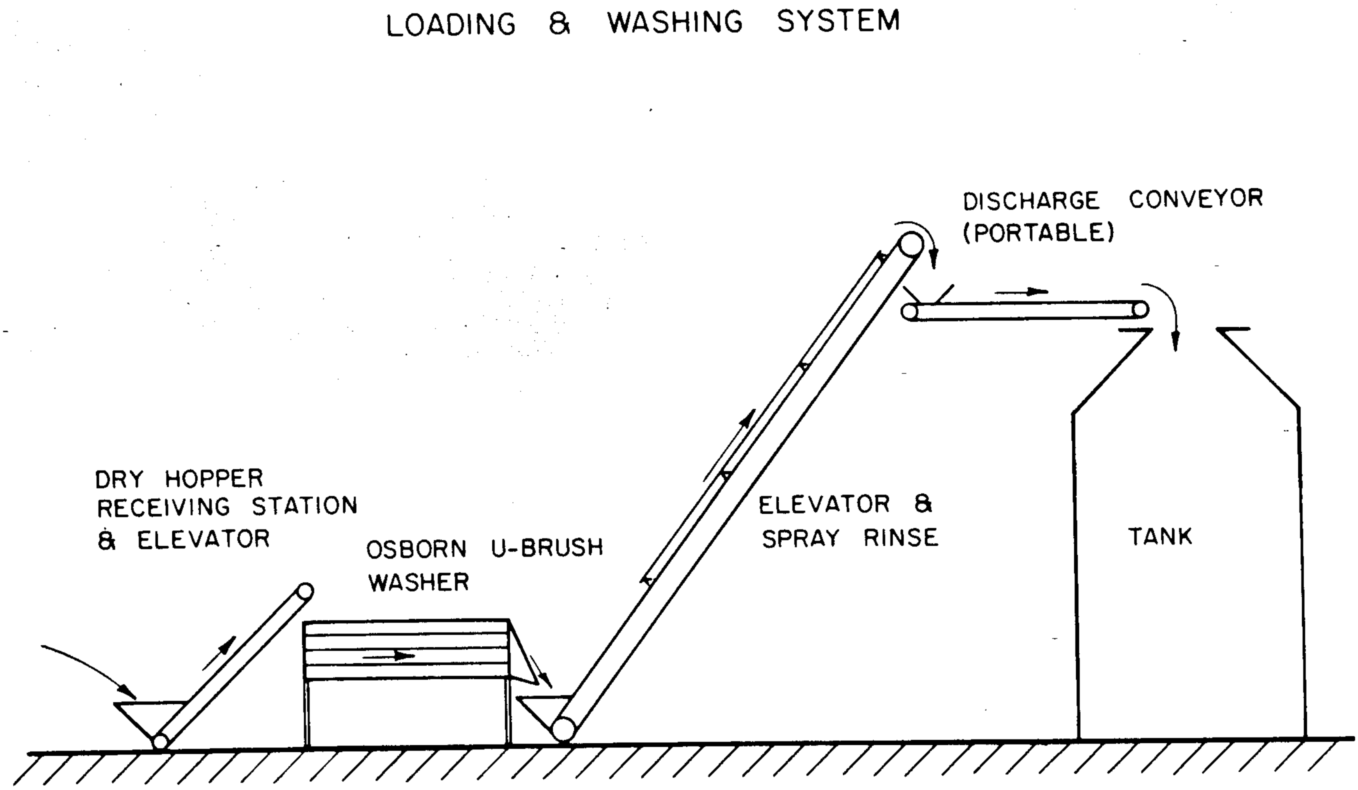


Fig. 3. Schematic diagram of components employed for washing and loading of cucumbers.

Brining

The cover brine was made up in a separate 550-gal, open-top tank and contained 40°S sodium chloride, 0.5% calcium chloride, and 0.4% acetic acid (added as 200 grain vinegar). These concentrations in the cover brine were intended to result in final concentrations after equilibration with the cucumbers at the 60:40 pack-out of 16°S sodium chloride, 0.2% calcium chloride, and 0.16% acetic acid. The cover brine was pumped through the side-bottom port of the brining tank which contained the cucumbers. After 24 hr, the brine was withdrawn from the brining tank into the brine makeup tank. The brine was adjusted to about pH 4.5 with sodium hydroxide. For the 1981 experiments, sufficient sodium chloride was added to the withdrawn brine to result in 22° S equalized with the cucumbers. No additional sodium chloride was added to the withdrawn brine in 1982 experiments.

After these brine adjustments, the brine was inoculated with 28 g of AFERM 772 (Microlife Technics, Sarasota, FL). This resulted in billions of cells of *Pediococcus cerevisiae* per gallon of brined cucumbers. After mixing, the brine was then pumped back onto the cucumbers.

Head devices

Green cucumbers are less dense than the cover brine, hence they must be restrained beneath the brine surface by a physical barrier or heading device. Two head devices were employed in the current studies, one constructed of wood slats and a second constructed of a hoop and net. The wood slat head was fabricated from 1¼ × ½ inch oak slats spaced on 1½ inch centers. It consisted of two semi-circular halves as shown in Figure 4a that were joined together with nylon bolts after insertion below the manhole neck in the tank top. Its top edge was beveled to approximate the incline angle of the tank top to attain a bearing surface on the tank. The hoop and net head device consisted of a stainless steel hoop approximately 27 inches in diameter, constructed from a ¼-inch rod and covered with mesh netting as illustrated in Figure 4b. The hoop had a 4-inch long sleeve and could be taken apart and collapsed to a diameter less than 24 inches so that it could be inserted in the tank top. After positioning below the manway neck, the two ends were rejoined to form a continuous circular loop that anchored the netting which in turn formed a nonrigid restraint to hold the cucumbers below the brine surface.

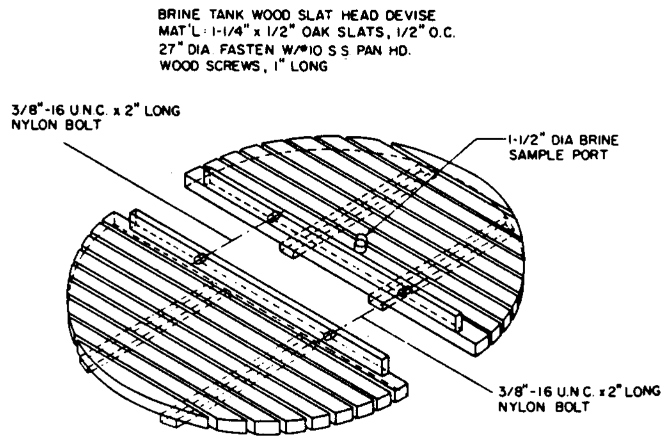
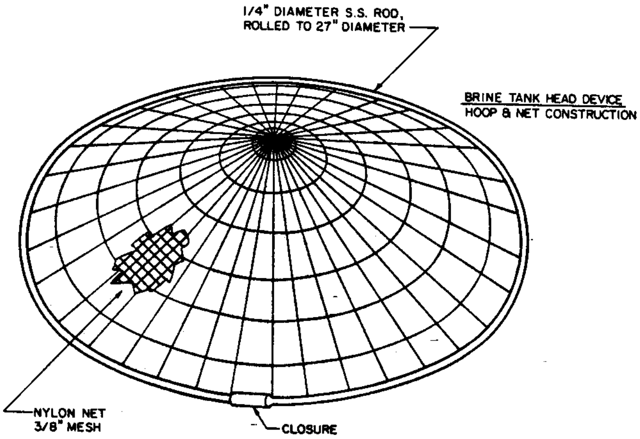


Fig. 4. Head devices: (a) Wood slat head device — semicircular construction of rigid sections allows for installation through manway opening; (b) Stainless steel hoop and nylon net head device.



Purging system

The purging system, schematically illustrated in Figure 5, consisted of a 4-inch PVC pipe permanently installed on the inside wall of the tank. The top was covered with plastic mesh netting, and the bottom intake section was 6 inches in diameter, thin wall PVC pipe perforated to permit brine, but not cucumbers, to enter the system. The nitrogen supply line was introduced through the tank wall by means of an internal threaded bulkhead fitting which also anchored the PVC pipe to the tank wall. The sparger was a 3½ inch section of 1½ inch diameter, porous plastic tubing having 10 μ pores and ¼-inch wall thickness, manufactured by Porex Technologies and connected to the bulkhead fitting via a short nipple and elbow. Nitrogen at 15 to 20 psi gauge pressure was supplied to the system, bubbled up through the vertical PVC pipe and essentially functioned as in a conventional tank. The 90° elbow at the top was included to impart a flow toward the tank center and exhaust port located in the top of the tank.

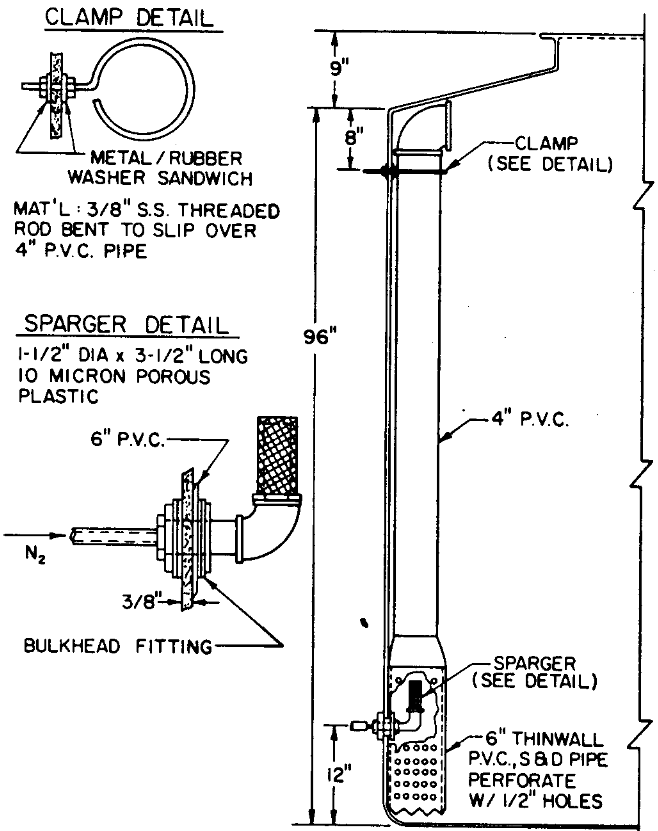


Fig. 5. Purger installation as mounted on interior of tank wall.

Anaerobiosis

The tank contents were isolated from the atmosphere by simply capping the manhole top of the tank. The cap was an inverted fiberglass tank some 24 inches in diameter and 18 inches high with a flanged section to mate it to the manhole top. In addition to isolating the brine surface from the atmosphere, the cap volume also provided a supply of brine for uptake by the cucumbers and accommodated other volume changes caused by temperature fluctuations. Its installation and operation are illustrated in Figure 6.

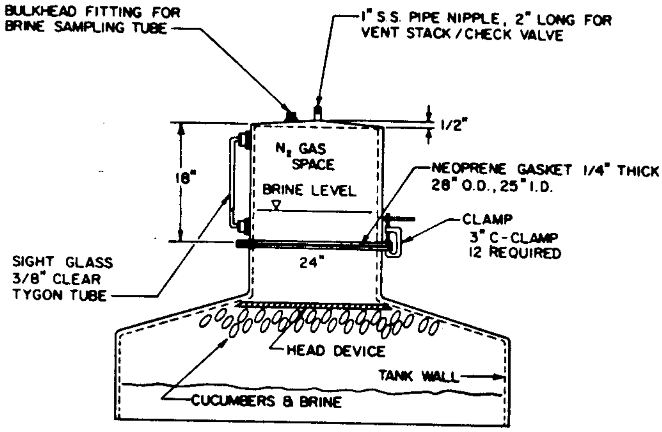


Fig. 6. Tank cap for manway opening illustrating nitrogen blanket space, brine level and head device installation in relationship to each other and cucumbers undergoing fermentation/storage.

After filling the tank with cucumbers, installing the heading device, and adding cover brine up to the neck of the manhole, the cap was secured to the tank by means of 12 C-clamps equally spaced around the matching flanges. A ¼-inch neoprene gasket between the flanges was included to insure a gas-tight seal. The brine level was then raised an additional 8 to 10 inches to provide a brine supply for uptake by the cucumbers. The top of the cap was outfitted with ports for venting the purging gases and installation of a brine sampling tube as illustrated.

During purging, which started immediately after brining, a 72-inch long vent stack was attached to the top of the cap to provide an escape path for the gases and to act as a bubble or foam diffuser. The stack also served to isolate the brine surface from atmospheric oxygen by providing an extended pathway for the escaping nitrogen which was concentrated at the brine-gas interface. Two stack diameters, 1 and 3 inches, were evaluated on the two tanks.

At the end of the purging period, the stack was removed and a low pressure (1 psi) check valve, model 4CP2-1 (Nupro Company), installed in its place for the storage mode. In this arrangement the nitrogen system for purging was left intact (at reduced pressure) and provided for a nitrogen blanket at the brine surface. At excessive pressure, the check valve would open and bleed the system to reduce pressure. Brine uptake by the cucumbers during the purging and storage periods was compensated for by the addition of nitrogen on a short-term basis and the addition of brine through the sample port of the cap on an "as needed" basis — usually about once a week during fermentation and less frequently afterward. Volume changes associated with temperature changes were quite small by comparison and were compensated for by the nitrogen supply and check valve system.

Brine sampling

A ¼-inch diameter (I.D.) stainless steel tube was mounted through the tank cap and protruded to the approximate center of the brining tank. The bottom of the tube which rested near the tank center was sealed. Four, ca. ⅛-inch diameter holes were drilled 1-inch apart, starting ca. 1 inch from the sealed end of the tube. Brine thus was sampled from the tank center by siphoning through the steel tube and through a flexible, polyethylene tube connected to the steel tube above the top of the tank. Samples were withdrawn with a 10-ml plastic syringe through a stoppered "T" placed in the polyethylene tube. The sampling procedure was similar to that described previously (Fleming et al., 1974). The samples were placed on ice and returned to the Food Fermentation Laboratory for analyses.

Chemical analyses

Brines were analyzed for CO_2 with the Harleco CO_2 Apparatus as previously described (Fleming et al., 1974); and for pH, titratable acidity, reducing sugar, and salt as previously referred to or described (Fleming et al., 1973).

Unloading system

The tanks were unloaded by brine floatation of the cucumbers out through the tank top. The brine level was lowered to a point just below the top manhole flange by draining through the tank bottom, the top cap removed, and an overflow unloading attachment installed as illustrated in Figure 7. The unloading attachment was a stainless steel (16 gauge) cylindrical section, 24 inches in diameter and 24 inches long with a mating flange for attachment to the manhole. A 12-inch diameter, side-arm overflow pipe at a 30° incline was provided as an exit tube for brine and cucumbers. A 5-ft section of fiberglass pipe, 12 inches diameter, was fitted to the overflow pipe and discharged to a brine-stock separator unit as indicated in Figure 7b and c. A schematic diagram of the entire unloading system is given in Figure 8.

The separation unit was basically a screening conveyor and brine collection tank. Cucumbers and brine were delivered to the intake end of the 24-inch conveyor, the brine drained from the cucumbers through the stainless steel mesh conveyor (Canbraidge Wire Cloth Company, Balanced Weave Metal Belting B-18-16-11) and collected in the holding reservoir below while the cucumbers were discharged from the separator conveyor to pallet bins handled by forklift.

To operate the system, brine 3 to 5° salometer greater than the tank brine was pumped into the bottom of the tank, causing cucumbers and the lighter cover brine to overflow into the side-arm pipe and onto the separator. The brine collected in the separator reservoir was subsequently recirculated by a separate pump to the top of the tank where it was discharged back to the tank contents. Theoretically, after the system stabilizes, the rate of cucumbers discharged from the tank is proportional to: 1) the rate at which heavy brine is added to the bottom of the tank, and 2) the rate at which brine is recirculated from the brine-stock separator.

Product evaluation

Fermented cucumbers were evaluated for balloon, lens, and honeycomb bloater damage according to Etchells et al (1974), and the total damage expressed as the bloater index according to Fleming et al. (1977). Means reported are from duplicate batches of 25 cucumbers per batch. Cucumber firmness was determined with a Magness-Taylor Fruit Pressure Tester equipped with a 5/16-inch diameter plunger. Means reported are from duplicate batches of 20 cucumbers each. Visual cure was estimated subjectively, and soft-centered cucumbers were determined by exerting finger pressure on the seed area of duplicate, 25-cucumber batches of longitudinally sliced cucumbers.

RESULTS AND DISCUSSION

System performance

The results reported herein were obtained during the 1981 and 1982 brining seasons. Results to date have been most encouraging in that we have been able to successfully load, ferment, store, and unload cucumbers utilizing the closed tanks.

Tanks

The two fiberglass tanks have served quite well as fermentation and storage containers; the tank walls/tops were easily drilled for accessory fittings used in connection with compression-type fittings; and there have been no serious faults or leaks except for one instance which was caused by carelessness. In this case, one of the tanks was partially collapsed near the top when its contents were drained without providing proper venting. Field repairs were easily made with fiberglass and resin.

The domed top is quite capable of serving as a heading device (except for the manhole) to restrain those cucumbers in the area it covers. The slope of the top section did not impede movement of cucumbers out of the tank through the manhole during unloading; however, these tanks were only 5 ft in diameter, and in larger tanks, a steeper top may prove necessary. These aspects of tank geometry will be experimentally investigated before specifying design parameters for commercial sized tanks.

Geometry of the manhole fitting may also be altered by extending the neck vertically in order to gain additional space above the heading device. Additional space is desirable to provide adequate brine uptake during the initial stages of fermentation and storage. The additional space may also eliminate the need for a stack-type vent to contain the foam/bubbles generated during purging. Marginal increases in tank wall strength may also be necessary to withstand the slight increases in pressure associated with the use of check valves during storage.

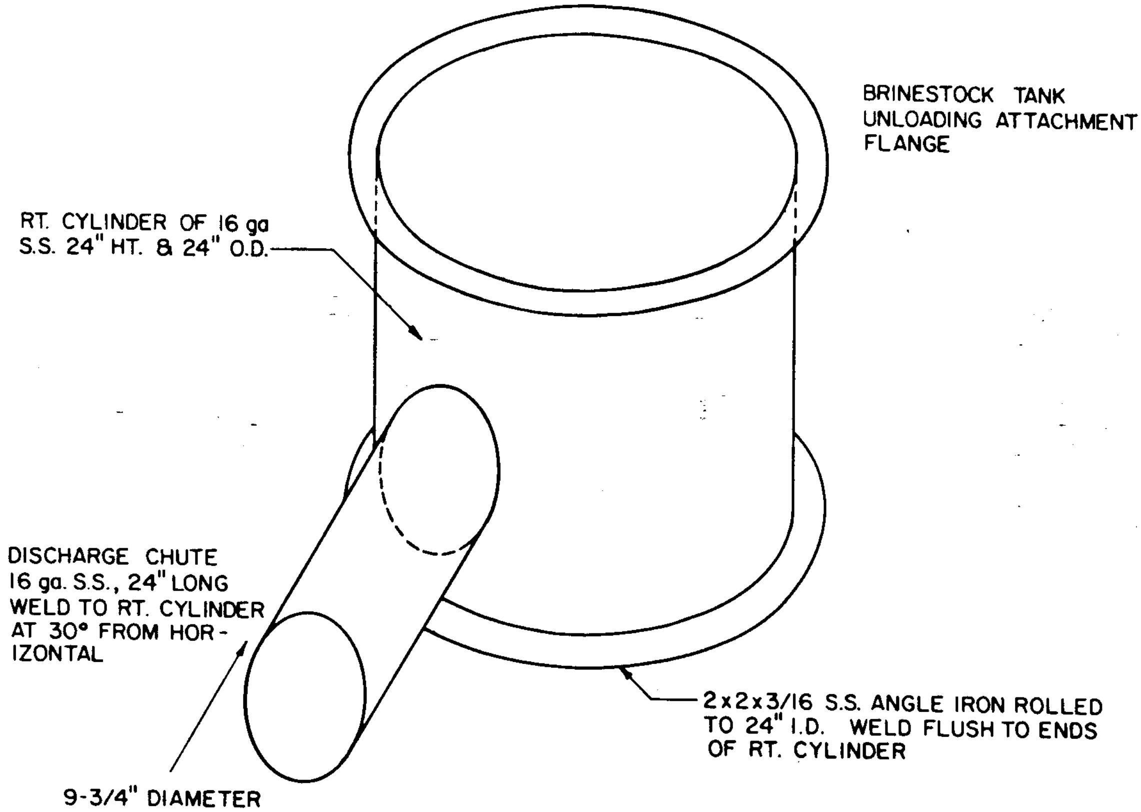
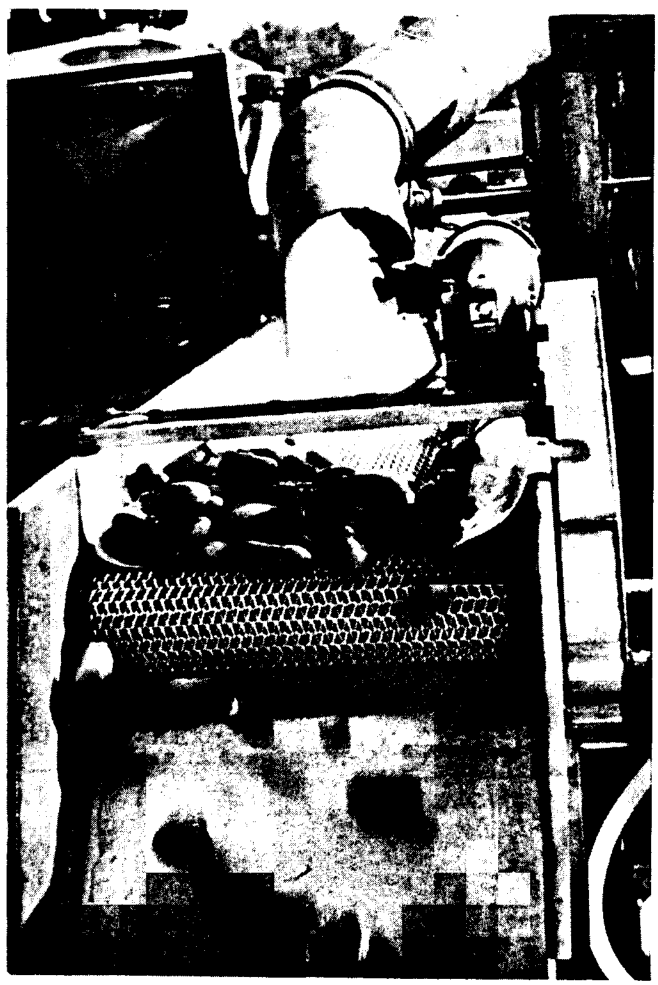


Fig. 7. Unloading of cucumbers by floatation out of the tanks into the brine separator: (a) Schematic of flange attachment; (b) Flange attachment installed in place of tank cap; (c) Discharge of cucumbers via conduit into the brine separator.



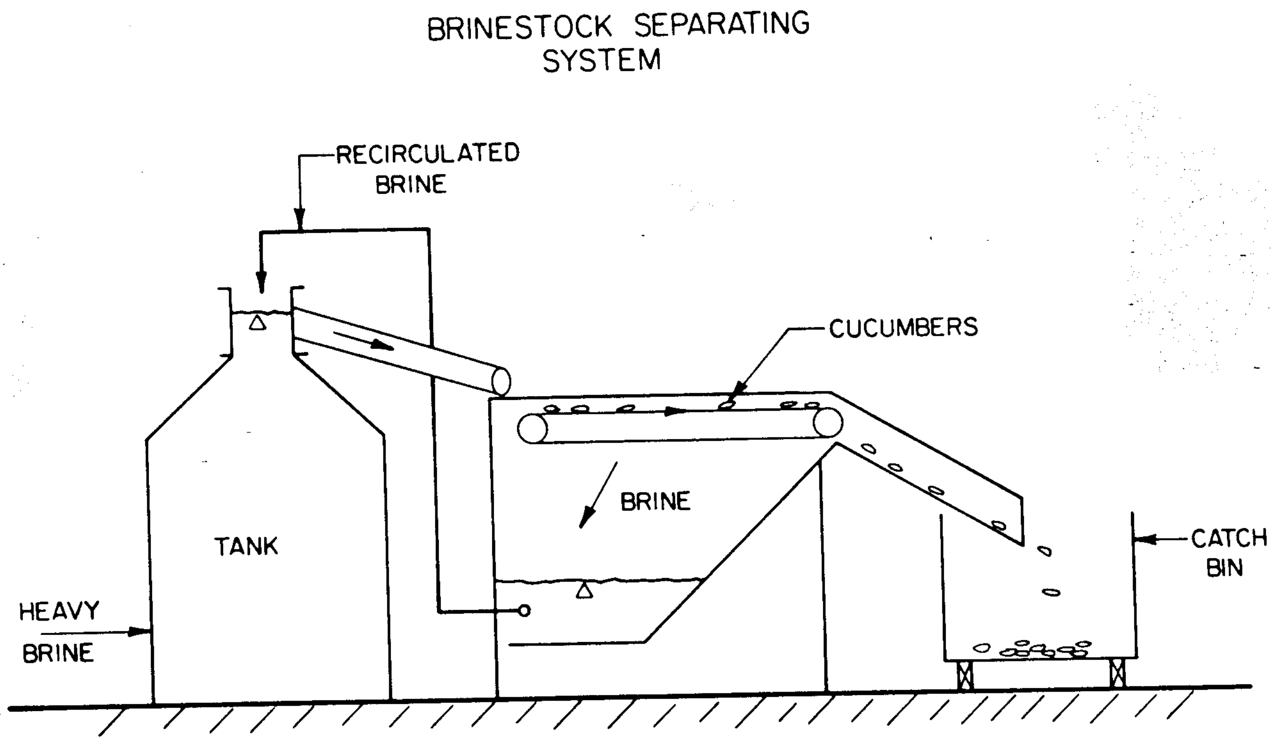


Fig. 8. Schematic diagram of components employed for unloading cucumbers from tank.

Loading system

The loading and washing system employed in these studies showed conclusively that cucumbers may be moved into tanks equipped with a manhole type opening. Obviously the capacity of the system is limited to the lowest capacity element in the line, which in the present case was the last conveyor discharging to the tanks. One and one-half to two bu per minute could be handled by the system as installed; it should be possible to design a system capable of moving up to 10 bu per minute through the manhole access port. Care should be taken to avoid conveyor losses over the sides or at transfer points from one conveyor to the next; problems of this type did occur with some frequency.

Washing

The cucumbers used in this study, being hand-picked, were relatively clean. Nevertheless, washing of the cucumbers removed a measurable amount of soil and other foreign material from their surface. Loosely adhering foreign matter was reduced nearly 90% (Table 1). Also, softening enzyme activity of apparent bacterial origin (pH 9.0) was reduced from significant amounts on the unwashed cucumbers to insignificant amounts on the washed fruit. None of the cucumbers in the four lots tested contained apparent softening enzyme activity of mold origin (pH 5.0). Although softening enzymes of bacterial origin are not generally thought to cause a problem in brined cucumbers because of the low pH conditions (Etchells et al., 1958), removal of bacterial enzymes in the study indicates effectiveness in the washing treatment.

Washing removed about 74% of the total loosely adhering bacteria, but about 98% of the lactic acid bacteria (Table 2). There was inconsistency in the effect of washing on *Enterobacteriaceae* counts with the first two batches of washed cucumbers showing a drop in counts and the last two a slight increase over the unwashed fruit. Washing may prove to be highly desirable, especially in the closed tank system, in spite of the additional work loads it would im-

TABLE 1.

Removal of foreign material and softening enzymes from cucumbers by washing*

Osborn wash treatment	Sample no.†	Foreign matter, mg/g cucumber	Softening enzyme, units/g cucumber	
			pH 8.9	pH 5.0
Not washed	1	40.1	202	0
	3	17.4	26	1
	5	22.3	5	0
	7	27.8	16	0
Average		26.9	62	
Washed	2	0.0	5	1
	4	2.1	2	0
	6	4.6	2	0
	8	5.2	1	1
Average		3.0	2	
Washed/unwashed		0.11	0.04	

*Foreign matter and softening enzyme activity in the saline wash solution of cucumbers before and after washing by the Osborn brush washer. See Materials and Methods for procedure.

†Cucumber samples were taken in the chronological order listed during the course of washing of cucumbers in the Osborn washer over a period of about 2 hr as the tanks were being loaded.

TABLE 2.

Removal of microorganisms from cucumbers by washing

Washing treatment	Sample no.†	Microorganisms/g cucumber* Total aerobes	Enterobacteriaceae	Yeasts & molds	Lactic acid bacteria
Not washed	1	875,000	19,625	2	1,787
	3	565,000	30,510	6	2,316
	5	529,000	18,081	3	1,267
	7	1,037,000	61,560	52	6,156
Average		751,500	32,444	16	2,882
Washed	2	68,265	7,770	<1	75
	4	132,210	5,537	<1	60
	6	142,600	21,275	<1	91
	8	399,600	106,560	<1	19
Average		185,669	35,286	<1	61
Washed/unwashed		0.26	1.13	—	0.02

*Microorganisms in the saline wash solution of cucumbers and after washing by the Osborn brush washer. See Materials and Methods for procedure.
†Cucumber samples were taken in the chronological order listed during the course of washing of cucumbers in the Osborn washer over a period of about 2 hr as the tanks were being loaded.

pose on the intake system during "green" seasons. It is our intent to develop a low-salt brining system that will greatly reduce or eliminate the need for desalting. It may even be possible to use the fermentation brine in the final product, similar to the procedure for genuine dills. For these reasons washing of the cucumbers before they go into the tank seems only logical. With this concept, the cucumbers can be considered a consumable product while they are in the brine tank. Washing can provide three distinct benefits: (1) removal of soil and other foreign material may reduce off-flavors and "gritty" pickles in the final product; (2) softening enzymes are removed, which will help to insure the possibility of low-salt storage; and (3) with assurance that softening enzymes are not present, the brine may be reused without special treatment.

Washing may well impose the necessity for inoculation of the brine with lactic acid bacteria, however. Although many thousands of total bacteria remain on the cucumber after washing, the number of desirable lactic acid bacteria may be reduced too low to insure a consistent, desirable fermentation. Less than 100 lactic acid bacteria per g of cucumber were left after washing (Table 2). Not all of the natural lactic acid bacteria on cucumbers are of the desirable type.

Head devices

Both head devices evaluated were capable of restraining cucumbers below the brine surface and, in general, functioned as intended. The wooden slat version was somewhat less convenient to maneuver into position than the hoop and net version which could be installed very quickly — less than a minute. The hoop and net confined the top surface of cucumbers to a domed configuration as opposed to a flat surface, but this presents no real disadvantage provided the brine surface is always above the most extended center area. Considering the relatively small load (buoyancy force) carrying capacity required, it is clearly feasible to mass produce either type from semi-rigid plastic or other synthetic materials at a nominal cost.

Purging system

Operation of the purging system presented no particular functional problems in that elimination of CO_2 from the brine was accomplished as expected. Flow rates were probably higher than necessary and a smaller sparger could be substituted, especially in small tanks. It is also suggested that the supply line be looped to an elevation higher than the tank top in order to prevent the hydrostatic head in the tank from pushing brine back to the pressure regulator when the system is inadvertently cut off. It is also suggested that the sparger assembly inside the tank be made accessible to inspection for leaks or clogging of the pores which might occur during periods of nonuse.

Anaerobiosis

The tank capping system, providing for a nitrogen blanket at the brine surface, functioned satisfactorily, but not without incident. The use of C-clamps for clinching the cap to the tank was a temporary measure and proved to be cumbersome; the clamps corroded quite rapidly, were difficult to operate, and required undue time and attention in their installation to achieve proper sealing of the cap-to-tank flanges. The nitrogen blanket concept provided for isolation from atmospheric oxygen and prevented growth of undesirable microorganisms, while the cap provided a physical barrier to contamination.

The vent stacks successfully contained foam generated during purging; foam was visible in the bottom third of the plexiglass tubes but was not pushed out their tops. There does not appear to be an advantage for the larger 3-inch diameter vent as compared to the 1-inch diameter, at least for the levels of nitrogen flow and foam generation experienced in these limited tests. The height or volume of gas space available in the cap above the brine surface, and the use of recycled brine, could influence the accumulation of foam in the vent stack.

The cap volume also has implications in overall tank design. Previous laboratory research (Fleming et al., 1980) has established that brine uptake during fermentation of cucumbers may be rapid (2 to 3 hr) and amount to as much as 5-7% of cucumber volume for cucumbers exposed to pure oxygen before brining. Similar results have been demonstrated in pilot tanks as noted in our companion paper in this issue (Fleming et al., 1983). Similar volumes of brine are also required for conventional brining procedures, but over a much longer period of time. Thus, for a completely self-sustaining system, the volume of extra brine in the cap space should be at least as large as the total brine uptake. At a 60% pack-out ratio of cucumbers, the cap volume should provide for 4 to 5% of the tank volume in extra brine storage in addition to providing for a nitrogen headspace to contain the foam that may be generated by purging. For a commercial size tank of 10,000 gal, these requirements translate to a cap volume of 500 gal — a fair size tank in itself. Alternatively, sufficient cap volume to handle the foam generation may be combined with a brine supply system stored in a separate anaerobic tank. The supply tank equipped with appropriate controls, could feed any number of fermentation tanks in a tank yard through a manifold system.

The maintenance of anaerobic conditions after cessation of purging depended primarily on the proper operation of the check valve system installed in place of the vent stack. Nitrogen pressure supplied to the purging sparger was reduced to 5 to 6 psi, which was only sufficient to overcome hydrostatic pressure and assure a positive pressure in the cap space. The check valves required more than 1 psi for cracking, and consequently, pressure on the order of 2 psi was occasionally observed in the cap space.

Fermentation chemistry

No unusual behavior was noted in fermentation of cucumbers in the closed tanks as compared to what we have found previously in open tanks. Final acidities and pH values were typical of those found with controlled fermentations in open-top, nonleaking tanks (Table 3). The rate of fermentation and the final pH were higher with cucumbers fermented in recycled as compared to fresh brine as expected because of the additional buffering created by partial neutralization of the recycled brine before use. The CO_2 concentration never exceeded 25 mg/100 ml brine in any of the four tanks tested (Table 3).

Unloading system

The tank unloading attachment and floating procedure for unloading the fermented stock functioned well. The heavier brine was pumped into the tank bottom at approximately 200 gal per minute and effectively forced brine and cucumbers out the tank top and into the side-arm delivery section at the same overall rate. Theoretically, at 60% cucumbers by volume, 120 gal per minute or 12.9 bu per minute should be the cucumber unloading rate. However, the system was not 100% efficient since brine and cucumbers were not pumped out in the exact ratio of the tank contents. The tendency was for proportionally more brine than cucumbers to overflow into the side-arm, resulting in an unloading rate of only 6 to 8 bu per minute. The entrance to the side-arm obviously contributed to some loss in efficiency since the intersection of the vertical cylindrical wall and the 30° inclined pipe was a pear-shaped port, and thus, restricted free movement of cucumbers into the side-arm. In order to maintain a uniform unloading rate, it was necessary to direct the output from the brine return line of the brine-stock separator unit into the general area of the side-arm pipe entrance, thus dislodging and breaking up any tendency of the cucumbers to bridge over the intake entrance. Unloading efficiency also decreased significantly near the end of the unloading cycle as the concentration of cucumbers in the tank was not sufficient to occupy the space in the unloading flange. Nevertheless, the tank contents (cucumbers) can be readily removed with these methods — in one case, only three cucumbers remained in the tank following the operation.

Cucumbers and brine were discharged from the fiberglass delivery pipe onto the separator conveyor, the brine was collected and recycled to the tank top, and the cucumbers were collected in pallet bins as planned. The conveyor speed and length should allow sufficient time for the product to thoroughly drain — about 1 min. In the current system, the overflow and side-arm delivery rate to the separator (the hydraulic part of the unloading system), had more capacity than the separator conveyor. Hence, pumping had to be periodically interrupted to prevent overloading of the separator conveyor. A reduced rate of pumping heavy brine into the bottom of the tank would have accomplished the same result. The slope of the delivery pipe, approximately 30° in this instance, was not a variable in this study, but it should be pointed out that quite rapid veloci-

TABLE 3.
Analysis of fermentation brines

		Maximum CO_2		Final brine analysis*			
Year	Fermentation brine	mg/100 ml brine	Day reached	pH	Acidity %	Salt %	Sugar %
1981	Fresh	25	5	3.19	0.98	6.2	0.04
	Recycled 1X	24	6	3.54	0.82	6.1	0.05
1982	Fresh	13	1	3.34	0.90	5.2	0.05
	Recycled 2X	12	1	3.54	0.92	5.1	0.05

*Determined 1 month after brining.

ties can be attained in relatively short sections as the motion of cucumbers and brine in the pipe was essentially frictionless.

Based on our experience and observations to date, it is obvious that significant improvements can be made in the unloading procedure. Unloading rates should be closely coupled to pumping rates and brine-stock conveyor capacity. Improvements in efficiency can be attained by improving the design of the side-arm pipe to the unloading attachment. Automatic controls on the pumping rate — into the tank and from the brine-stock separator back to the tank top — should also be considered. Nevertheless, the present system was capable of unloading at reasonably high rates without inflicting mechanical damage to the product.

Product quality

Overall, cucumbers fermented in closed tanks in both fresh and recycled brine were of acceptable quality. The bloater index was about 10 in the upper ⅓, but was about 1 or less in the middle and bottom sections of the tanks (Table 4). Similar observations have been made in open-top, wooden tanks (Fleming et al., 1977; 1983); thus, we do not attribute this depth effect to the closed tank. Firmness of the cucumbers was slightly higher at greater depths, perhaps a reflection of the lower bloater damage. Soft-centered cucumbers were present in the tank containing recycled brine, but were not detected in the tank containing fresh brine. It was unclear if use of recycled brine caused soft center development, however, since the tanks were filled 1 day apart with different lots of cucumbers. The yield of fermented cucumbers from three separate fermentations over a 2-yr period varied from 94 to 99% of the fresh cucumber weight.

Firmness changes during storage

The firmness of cucumbers stored up to 1 yr in the closed-top tanks was quite acceptable and was within 2 lbs of firmness readings taken after 2 months of storage (Table 5). Firmness readings were similar for cucumbers fermented and stored in fresh and in recycled (1X) brine. Samples of cucumbers were taken 2 months after brining and held under laboratory conditions. The salt strength was increased in a portion of the cucumbers to 45 ° S, which approximates the salt concentration used by many companies for long-term storage. Interestingly, firmness was not greatly different for cucumbers stored at the low or at the high brine strengths with fresh brine for fermentation; firmness was reduced during storage, however, at 22 ° S in the recycled brine.

FUTURE STUDIES

Although satisfactory progress has been made to date, full success of the project depends upon studies yet to be performed. In fact, we are not committed to any of the design features of the brining tank or the handling system. We are purposely holding options open at this point in order to take advantage of better ideas as they are developed or brought to our attention. Individuals and commercial firms will be solicited for their contribution of ideas and equipment to effect a more efficient tanking and handling system. Further engineering and biological/product research is presently underway or planned.

Engineering research

Considerable research remains on the most effective method for assuring anaerobiosis. An improved manway cover, foam control during purging, and methods of com-

TABLE 4.
Effect of tank location on firmness and bloater damage of brined cucumbers*

Fermentation brine	Tank location	Firmness, lbs (CV)†	Bloater index	Visual cure, %	Soft centers, %
Fresh	Top	19.8 (16.5)	11.4	100	0
	Middle	20.6 (12.0)	0.8	100	0
	Bottom	21.0 (9.6)	0.2	100	0
Recycled	Top	19.1 (12.5)	8.6	100	12
	Middle	19.2 (13.9)	1.4	100	12
	Bottom	19.4 (14.6)	0.2	100	20

*Evaluation was made 12 months after brining.
†Coefficient of variation in parentheses.

TABLE 5.
Firmness of brined cucumbers stored in pilot tanks under ambient conditions and in gallon jars under laboratory conditions

Fermentation brine	Storage location	Temperature (°F)	Salt (°S)	Firmness, lbs*		
				2 months	6 months	12 months
Fresh	Pilot tank	Ambient	22	20.8 (13.8)		19.8 (16.5)
	Lab	78	22		20.4 (12.4)	19.3 (11.3)
	Lab	78	45		20.0 (14.3)	18.4 (17.3)
Recycled	Pilot tank	Ambient	22	21.0 (13.6)		19.1 (12.5)
	Lab	78	22		19.4 (17.4)	15.8 (24.6)
	Lab	78	45		20.0 (17.3)	19.0 (12.1)

*Pressure test readings taken after 2, 6 and 12 months of storage at 78 °F. Coefficient of variation in parentheses.

pensating for brine volume changes are under study. Application of our findings to large-scale tanks for commercial use is being considered. Thus, manway placement, slope, and other design features of the tank cover are under study, as is overall tank size and geometry. No options have been closed as to the type of material for tank construction. The loading/unloading system must be adapted to large tanks. Design features for covers to be adapted to existing, open-top fiberglass tanks is under consideration. Freezing problems and methods for controlling the problems, such as above/underground placement, sheltering, or other means must be considered since fermentation and storage at low salt concentrations is projected. Finally, pH, temperature, brine volume, and other control systems must be suitably applied.

Biological/product research

The anaerobic tanking system opens a new era for brining research. We are already thinking in dimensions heretofore considered impractical. We will be investigating methods for minimizing salt usage. This includes lower salt usage during storage and brine recycling and/or direct use in the final product. Methods for tank and product washing and sanitization will be studied. Finally, we anticipate that novel microorganisms will be developed for use in conjunction with the anaerobic tank, which will result in improved product flavor and overall quality. It is hoped that the pickle industry will be in a position to take advantage of potentially revolutionary methods for preserving vegetables.

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