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Anaerobic Tanks for Cucumber Fermentation and Storage

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Fermentation in sodium chloride (NaCl) brine by naturally occurring micro-organisms is an established procedure for temporary preservation of cucumbers in open-top tanks. The physical attributes and accessory supporting equipment of an anaerobic, closed-top tanking system with the potential to reduce environmental problems and facilitate the use of new fermentation technology is reviewed and updated. Prototype tanks of 30 to 35 m^3 capacity and fibreglass construction having a food-grade liner were selected for introductory stage testing and semi-commercial evaluation. Anaerobic conditions were achieved by sealing the manhole port located at the tank top and purging the brine with nitrogen (N_2) gas to remove oxygen. The purging (at rates up to $1{\cdot}0\,m^3/h$) served to remove carbon dioxide (CO_2) generated during fermentation and also operated as a gas lift pump to circulate the cover brine. During fermentation, N_2 and CO_2 gases were vented from the tank top through a 50 mm diameter vent tube at atmospheric pressure. During storage, anaerobic conditions were maintained by a slight (approximately 250 mm water column) positive pressure of N_2 in the headspace above the liquid level; a U-tube manometer served as a means of isolation, a pressure indicator and a safety device against excessive positive or negative tank pressures. Field trials to the system under commercial conditions have demonstrated that anaerobic tanks can alleviate many of the objectional features of open-top tanks. Implications of projected modifications of the system are briefly examined.

1. Introduction

Production of pickling cucumbers in the United States is approximately $5{\cdot}8 \times 10^8$ kg annually, which requires $4{\cdot}5 \times 10^4$ ha of crop land.[1] Commercial processors temporarily preserve about 40% of the crop by fermentation in NaCl brines[2] in which fermentable carbohydrates are converted to lactic and acetic acids, ethanol, CO_2, and traces of other compounds by naturally occurring lactic acid bacteria and yeast. The process serves to extend the use of packing line equipment and labour to an all year round operation in the manufacture of finished product. Conventionally, open-top wood, fibreglass, or polyethylene tanks up to 76 m^3 capacity are employed for fermentation which may require 10 to 21 days; storage periods (in the same tank) are usually less than one year, but may be longer. The tanks are held outdoors to allow ultraviolet irradiation from sunlight to strike the brine surface which inhibits growth of moulds, yeasts, and other oxidative micro-organisms on the brine surface.

Sodium chloride serves two primary functions in the preservation of cucumbers by fermentation; it regulates the type of microbial activity, and it prevents softening and other degradative changes in the tissues. Conventionally, 5 to 8% NaCl (based on total weight of tank contents) is present during the fermentation stage and may be increased to 12 to 16% for storage as a precaution against spoilage since the open-top tanks are exposed to contamination and rainwater dilution. Since only 1 to 4% NaCl is desired in finished pickle products, the excess salt must be disposed of during further processing.

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Sodium chloride disposal is becoming an increasingly serious problem due to its contamination of fresh surfacewater and groundwater. The US Environmental Protection Agency recently proposed[3] that chloride limits in streams or lakes should not exceed 230 mg/l. Typical wastes from commercial pickle operations in the US may exceed that value by 100-fold. Thus, unless the flow (or capacity) of the freshwater stream (or lake) into which the effluent from the pickle company is discharged is of sufficient volume to dilute the freshwater-waste mixture to the 230 mg/l limit, the company could be forced to reduce or cease operations.

Co-operative research among the NCSU Biological and Agricultural Engineering and Food Science Departments at North Carolina State University, the United States Department of Agriculture, Agricultural Research Service, and Pickle Packers International, Inc. has developed and put into operation experimental anaerobic (closed-top tanks with N_2 headspace) tanks for fermentation and storage of cucumbers at ten locations throughout the USA and Canada. Anaerobic tanks provide protection against contamination by rainwater and foreign matter and permit the use of less salt in cover brines since rainwater dilution is eliminated and exposure to spoilage agents reduced. Thus, they represent an important element in overall salt reduction strategies. It is perceived that anaerobic tanks also offer a means of manipulating the fermentation process through added cultures that is not feasible with open-top tanks.[2,4–6] The potential for improving product flavour, colour and texture along with development of new pickled products or further use of the cover brine is a major impetus for anaerobic tank research and development.

Economic factors associated with the use of anaerobic tanks have not been examined in detail. There are some direct cost comparisons with open-top tanks that can be evaluated, i.e. closed-top tanks cost approximately one-third more than similar open-top tanks. Installation costs are essentially equal while operating costs for labour and materials may favour open-top tanks. However, the dominant considerations associated with closed-top tanks are the intangible benefits related to salt reduction, sanitation, and potential for new or improved products as mentioned above.

This paper is a review[2,5–7] of pertinent physical design features of anaerobic tanks and updates operating features or accessories that have been evaluated in recent non-replicated field trials. Projections of probable changes in system parameters and their implications for tank design are also discussed.

2. Functional requirements

The essential features of anaerobic tanks as currently operated are schematically illustrated in *Fig. 1*. Design strength is for a thin shell, low pressure vessel (less than 6·85 kPa in the gas headspace at tank top) filled with a 1·1 specific gravity liquid. Materials of construction (fibreglass or high density polyethylene), tank geometry, accessories, critical dimensions, and product handling methods for loading/unloading cucumbers are discussed in earlier publications.[2,6,7] The 35° slope (*Fig. 1*) is related to the angle of repose for cucumbers and is the minimum inclination of the tank top that will accommodate loading of cucumbers without creating void spaces at the outer regions of the tank.[6] Related aspects including pretreatment washing, brine make-up, added cultures, methods of monitoring the fermentation and product evaluation have also been reported.[2,5,7]

Briefly, closed-top tanks are filled with approximately 60% cucumbers and 40% cover brine (volume basis) and sealed at the manhole. The cover brine is typically 10% NaCl (by weight) which results in a final equilibrium concentration of approximately 4% throughout the cucumbers and brine. No additional salt is added for storage; by way of

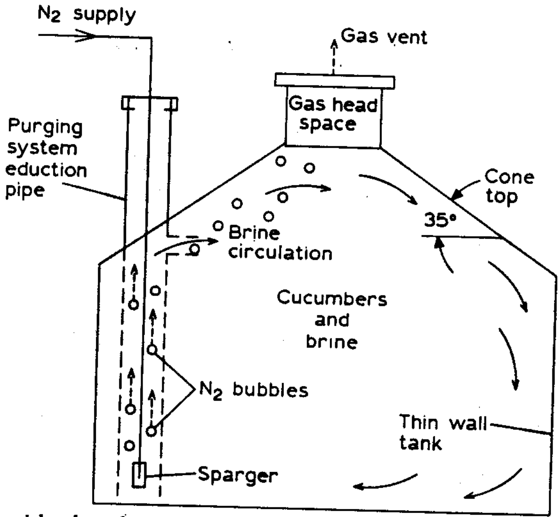

Fig. 1. Anaerobic tank with closed, cone shaped top and side-arm purging system as employed in experimental tanks. Tank diameter is 3·66 m and overall height is 3.55 m providing a usable tank volume of 31·4 m³ with a capacity of 19 tonnes of cucumbers

comparison, this is less than half the salt utilized in conventional open-top tanks for the storage phase during which additional salt is added. The brines are purged with N_2 gas during the fermentation stage (10 to 21 days, depending on temperature) which removes dissolved CO_2 and circulates the brine to maintain uniform conditions throughout the tank.[7] High CO_2 concentrations have been associated with formation of destructive gas pockets in cucumbers referred to as "bloating" by the industry. It has been established that dissolved CO_2 concentration in brines should be limited to 30 to 50% of saturation which depends on salt content and temperature.[7,8] Following fermentation the system is switched to the storage mode by restricting escape of the purging gas and establishing a positive pressure equivalent to about 250 mm of water column in the headspace. Positive pressure prevents the inadvertent entry of atmospheric oxygen into the headspace. From an overall system perspective, the most important design requirement is for a non-leaking vessel capable of maintaining anaerobic conditions at low pressure.

2.1. *Fermentation mode*

Anaerobic conditions are established by purging as soon as possible after filling the tank. The manhole is sealed with a rigid cover attached to the tank top by means of a flanged connection; a gasket is required for a gas tight seal. Best results have been attained with a flat 6 to 9 mm thick neoprene gasket sandwiched between the cover and tank flanges. Contact pressure between the flanges can be applied by evenly spaced clamps or bolts; a minimum of six to eight are required depending on cover rigidity and manhole diameter. Alternatively, a centre post and hanger assemble that grips the tank flange and applies compressive force to the centre of the cover may be employed. Post and hanger mechanisms generally require more uniform mating between the flange faces of the tank and cover but facilitate quicker opening and closing than perimeter fasteners. In view of the small internal pressures involved, a simple quick release barrel or band clamp should be adequate.

The manhole cover also is equipped with pipe/tube fittings for addition of brine, brine

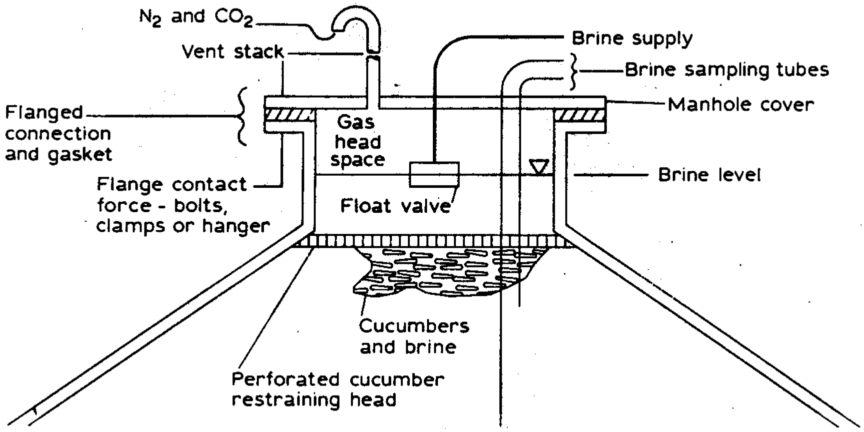

Fig. 2. Details of manhole cover, gas space in tank top, vent stack, brine supply and sampling lines during fermentation. The vent stack is restricted (or removed) during storage

sampling tube(s), and venting of N_2 and CO_2 to the atmosphere as illustrated in *Fig. 2*. An additional supply of brine is required to compensate for the absorption of brine into the intercellular spaces of the cucumbers, which is 5 to 7% of the cucumber volume;[9,10] thus for a 60/40 tank volume packout ratio, 7·5 to 10% additional brine volume must be supplied over a period of several days or weeks depending on temperature.

A plastic float valve (Little Giant Trough-0-Matic, Miller Manufacturing Co., 494 Villaume Ave, South, St Paul, MN 55075, USA) used for livestock or poultry watering systems has proved to be effective for adding brine and maintaining the liquid level. It is recommended that the valve body be encased in nylon hardware cloth to prevent cucumber seeds or other particulate matter from impeding its action. The additional brine may be gravity fed or supplied from a pressurized source. The float valve should be positioned to maintain the liquid level 100–120 mm above the cucumber restraining head to assure that cucumbers are covered with brine at all times.

Brine sampling tubes are installed at the time of tank loading and are used to siphon brine from various locations in the tank. The samples are analyzed to monitor or chart the progress of fermentation. Sampling tubes are typically 6–9 mm diameter stainless steel tubing (in the cucumber–brine mixture) connected to flexible vinyl tubing leading through the manhole cover to the tank exterior. Their installation and sampling procedures have been detailed in a prior publication.[7]

During fermentation N_2 purging gas at the rate of 0·5 to 1·0 m^3/h (standard conditions) is introduced into the tank through a sparging unit located inside an eduction pipe (*Fig. 1*) near the tank sidewall.[4,6,7,11] The system also constitutes a gas lift pump to circulate the brine within the tank at 1·5 to 3 m^3/h. Concurrently, the N_2 bubbles take up CO_2 from the brine. Brine circulation rates are not measured directly but may be calculated[12] based on eduction pipe parameters and the gas flow rate which is measured by a flow meter installed in the supply line. The gas components rise to the tank top, collect in the gas headspace above the brine and are vented to the atmosphere through a 1·5 to 2 m long by 50 mm diameter vent stack (*Fig. 2*). The vent stack tends to isolate the tank interior from atmospheric oxygen, especially during short time periods when the N_2 supply may be interrupted. Although the vent stack is open to the atmosphere, an additional two-way pressure relief valve (not illustrated) capable of opening at minimal pressure differentials is recommended to provide backup protection for the tank.

The restraining head device (*Fig. 2*) assures that the cucumbers are submerged in brine at all times. It must be removable to allow loading and unloading of cucumbers and it must be capable of withstanding the buoyancy forces of fresh cucumbers in brine which are of the order of 1750 N/m^2 for tanks 2·5 m deep.[6] Perforated plywood or PVC (in removable sections) 15 mm thick as well as nylon netting stretched over a semi-flexible hoop[2] have been used successfully.

2.2. *Storage mode*

Two important changes are made in the system to switch from the fermentation to storage mode while maintaining anaerobic conditions. The vent stack is closed and supply pressure to the N_2 purging unit is reduced. The N_2 regulator pressure should be set to a level that maintains a slight positive pressure in the gas space at the tank top (less than 250 mm of water column). At these conditions the N_2 flow rate through the purging unit is essentially zero (assuming no leaks) and atmospheric oxygen is excluded. The tank is quite vulnerable to pressure changes, positive or negative, that may occur due to malfunction of the float valve, N_2 pressure supply, or thermal expansion/contraction effects and means of protecting against slow pressure changes are necessary.

Long term storage under anaerobic conditions with structural protection for the tank has been achieved by employing a U-tube manometer with overflow reservoirs. One manometer leg is connected to the gas space in the tank top and the other leg to the atmosphere as illustrated in *Fig. 3a*. Since the vent stack is not required during the storage mode it may be removed and its port through the manhole cover used to connect

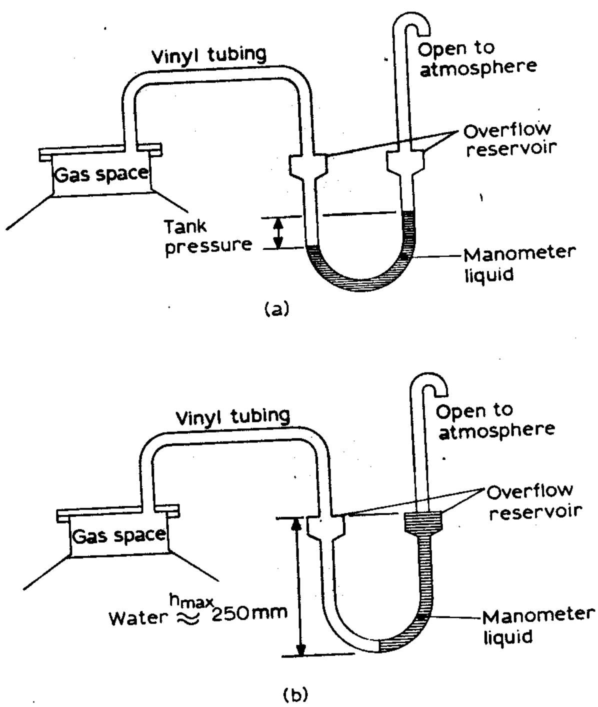

Fig. 3. (a) Simple manometer and reservoir system employed to indicate tank pressure conditions during storage. (b) Maximum positive tank pressure before release of N_2 gas to the atmosphere

the manometer. In practice, a column length of liquid is placed in the manometer that corresponds to the maximum pressure differential (positive/negative) that the tank can safely tolerate. As tank pressure increases, liquid is forced to the atmospheric leg until maximum pressure (h_{max}) is developed (*Fig. 3b*). Any additional increase in pressure allows N_2 to escape to the atmosphere by bubbling through the manometer liquid. The reservoir serves as a collector for the liquid and prevents it from being blown out of the manometer. After the pressure has been relieved the liquid drains back down the U-tube and the process begins anew. Negative tank pressure is much less likely to occur but is compensated for by reverse operation of the manometer. In this case atmospheric oxygen could be sucked into the gas space and should be removed by operating the purging unit (with an open port in the tank top) to supply a new charge of N_2 in the gas space. The manometer provides a quick, easy to read indication of pressure conditions and adjustments can be made in most instances before limits are reached if frequent (daily) examinations are made. Addition of a food grade dye makes the liquid column much easier to read.

The manometer-reservoir system described above has been used extensively on closed-top tanks and has successfully compensated for moderate pressure changes that occur. Vinyl tubing, nominally 10 mm in diameter, has been employed in combination with reservoirs of 50 to 60 mm diameter by 150 mm long; this combination provides sufficient reservoir diameter and volume to prevent liquid blow out. In temperate zones water or brine may be used in the manometer. Under freezing conditions, salt may be added up to 23·3% by weight (eutectic point) to provide protection against freezing[13] down to −21·1°C. It should also be noted that the manometer-reservoir system is not generally suited for potentially catastrophic pressure changes. Therefore, the backup pressure relief system employed during the fermentation should be kept in place.

3. Future considerations

The anaerobic tank system as described here and in cited references has been functionally successful in commercial prototype applications. Expanded use of the technology could be significantly advanced by engineering improvements in several subsystem or component areas. Three areas merit discussion here as they may influence tank design.

3.1. *Product handling*

Conventional materials handling equipment, including mechanical conveyers or fluming methods, are quite adequate for loading anaerobic or closed-top tanks through the manhole at rates of 100–200 kg/min. Flotation methods[2,6] for unloading can achieve similar rates and work well when properly executed to unload a tank in a short time (approximately 2 h are required to unload a 31·4 m^3 tank). However, several processors have indicated that closed-top tanks will become an integral part of their post fermentation/storage processing equipment and that partial unloadings (over several days) will be necessary. Under these conditions, unloading by flotation methods and the associated higher salt brines utilized negates one of the main advantages of closed-top tank technology, i.e. low salt content and usage.

Mechanical pumping is one alternative method but is cumbersome to prime and restart after a tank has been partially emptied. High capital costs, equipment maintenance and mobility are also unfavourable for mechanical pumping systems. Other possibilities include gas-lift devices or the use of a pressurized gas space above the liquid level to induce flow through a large dip pipe. Tank design changes, especially increased wall strength, would be required to implement the latter.

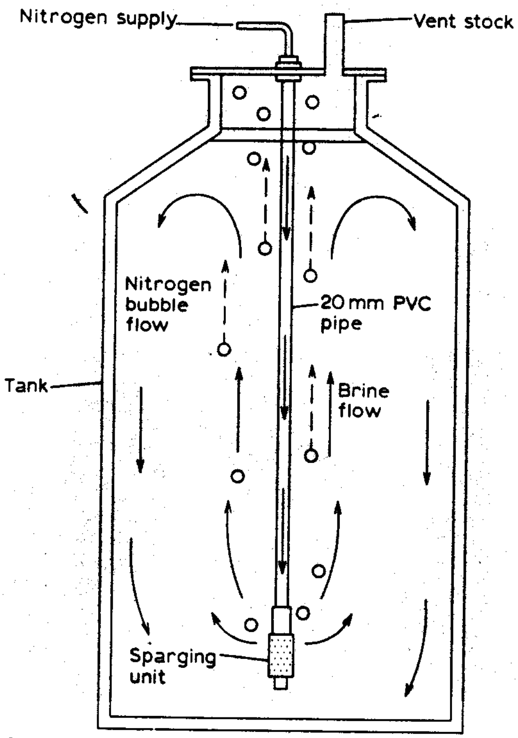

Fig. 4. Simplified purging unit without eduction tube as installed in test tanks

3.2. *Purging system*

Purging rate and system efficiency have not been optimized to obtain maximum removal of CO_2 for minimum N_2 usage. The basic 'side-arm' purging unit[8] is operated at N_2 flow rates up to $1{\cdot}0\ m^3/h$ during the fermentation phase. Theoretically, less than 10% of this amount is required for taking up the CO_2 generated during fermentation.[7] Limited field studies were conducted in 1986 and 1987 of a purging system that releases N_2 bubbles at the tank centreline, near its bottom, into the cucumber-brine mixture without use of an eduction pipe as illustrated in *Fig. 4.* This simplified system maintained safe CO_2 levels even at reduced N_2 flow rates. Further study and verification of the system is necessary but prospects for increasing purging efficiency and simplifying tank design by elimination of the eduction pipe and fittings are favourable.

3.3. *Hydrostatic pressure*

Laboratory studies[14] in 1977 established that CO_2 in the brine of fermenting cucumbers could approach saturation levels without adverse bloating effects if hydrostatic pressure was sufficiently high. Field studies at a co-operating processor's facilities during the last two years support this finding in that CO_2 levels approaching 100% saturation at hydrostatic pressures equivalent to a water column of 3 m showed no adverse bloating effects. Increased tolerance for CO_2 may be significant even at pressures as small as 1 m of water column. The implications of this are far reaching with respect to tank design. If the use of increased pressure is adopted, then increased tank wall strength will be necessary to accommodate the additional pressure. The additional pressure could be attained by a simple standpipe extending upward from the tank or by operating the gas headspace (*Fig. 2*) at a higher pressure.

4. Conclusions

Design features of closed-top tanks and accessories were capable of maintaining anaerobic conditions during fermentation and storage of pickling cucumbers. In comparison to conventional open-top tanks, closed-top tanks can reduce effluent discharge problems through the use of less salt, provide added protection against contamination from foreign materials, and enhance development of new or improved finished products. Anaerobic conditions were attained by sealing the tank against atmospheric oxygen and providing a means for purging with N_2 to remove CO_2 generated during fermentation. A system for blanketing the gas headspace with N_2 maintained anaerobiosis and provided protection against tank pressure changes during storage. Improvement and simplification of purging equipment is possible. The potential operating advantages of increased tank pressure during fermentation and unloading operations will require an increase in tank wall strength.

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