FLEXIBLE RESTRAINING COVERS FOR CUCUMBER BRINING TANKS

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ABSTRACT

Buoyancy relationships as related to brining of cucumbers in large tanks were examined. Forces acting on conventional, rigid head structures currently used by processors to restrain or keep cucumbers submerged in the brine are shown to range from 435 to 2825 N/m^2 (9.1 to 58.9 lb/ft^2) of tank top area. An alternative head structure consisting of an impervious, flexible cover for isolating the tank contents from its surroundings and weighted with a liquid overlay ballast is described. The alternative system, using 0.114 mm (4.5 mil) polyethylene sheeting and water or brine as the overlay ballast liquid, was experimentally evaluated in three commercial size tanks. While improvements in the cover design and its accessory connections are desirable, the overall technique was successful in keeping cucumber submerged. Furthermore, the alternative system has potential for savings in labor and materials and for converting conventional open-top tanks to anaerobic operation.
KEYWORDS. Fermentation, Tanks, Covers, Brine, Cucumbers.

INTRODUCTION

Cucumbers and other vegetables are often brined in salt solutions for fermentation and subsequent storage as a temporary means of preservation before processing into finished products. Brining is usually in large tanks constructed of wood, fiberglass, or polyethylene. Raw vegetables, especially cucumbers, are buoyant in brine and must be physically restrained below the brine surface for successful fermentation and storage. Conventional head structures (fig. 1) for restraining cucumbers below the brine surface usually are constructed of boards/timbers fitted to the tank top. The uniformly distributed buoyancy load (Humphries and Fleming, 1986) is resisted by flexure of the head structure and is transmitted to the tank wall through anchors located around the tank perimeter. Structural failure is infrequent but may be characterized by sudden fracture of the head boards exposing any nearby personnel to potential injury.

Installation of the head structure after the tank has been filled and its removal prior to unloading are significant costs; other economic factors include storage, maintenance, and replacement. In addition, the head structure does not provide protection from contamination by insects, birds, and other foreign agents as it allows an exchange of brine from above the head structure to that below. Furthermore, controlled fermentation procedures (Etchells et al., 1973) and more recently developed anaerobic techniques (Fleming et al., 1988) are not well suited to open-top tanks equipped with conventional head structures. Closed-top anaerobic tanks with rigid integral tops (Humphries and Fleming, 1988, 1986) alleviate the disadvantages of head structures, but their use has been limited by their additional cost and extensive changes required in materials handling operations for loading and unloading tanks.

Plastic tank covers, weighted with water or weak brine, have been used to restrain cabbage during sauerkraut fermentation for many years (Pederson and Albury, 1969). The use of such covers is believed to improve sanitation and product quality, since a properly weighted cover provides anaerobic conditions that minimize oxidative changes and spoilage organism activity. However, gases formed in the early stages of the fermentation may be trapped in the bulk pile of cabbage and result in heaving and generation of excessive uplifting forces that disrupt the cover and overlay liquid (Fleming et al., 1988).

The current study was designed to determine the feasibility of using flexible covers for restraining cucumbers in bulk tanks during fermentation and storage. The physical system was analyzed by considering buoyancy laws and properties of brine and cucumbers. It was shown that a flexible impervious cover could be used as an alternative to conventional rigid head structures; it

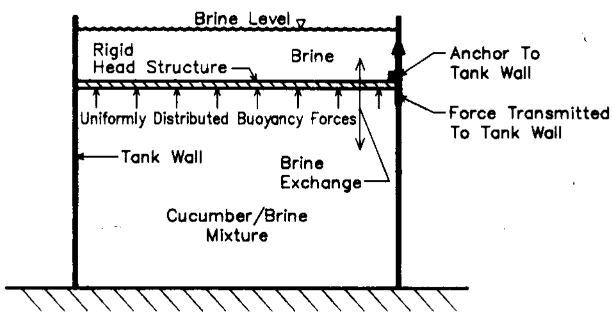

Figure 1–Schematic of a conventional open-top tank and head structure illustrating liquid level and buoyancy forces.

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also has potential for converting open-top tanks to anaerobic operation.

Buoyancy Relationships

Archimedes' well known buoyancy law states that an object immersed in a fluid will experience an upward acting force equal to the weight of fluid displaced. The difference between the weight of the object and the buoyancy force represents the force necessary to restrain or completely submerge a floating object (e.g., a cucumber in salt brine) in a liquid medium. Neglecting density changes due to depth, the restraining force (R) necessary to submerge a bulk pile of cucumbers in salt brine can be expressed as:

$$R = F\ \rho(\Delta s)\,\pi\, r^2 h \qquad (1)$$

where

- F = volume fraction occupied by cucumbers (pack-out ratio),
- ρ = specific weight of water,
- Δs = difference between brine and cucumber specific gravity,
- r = tank radius, and
- h = height of the cucumber bulk pile in the tank.

The restraining force per unit area (Pr) acting on the head structure may be expressed as:

$$Pr = F\ \rho(\Delta s)\, h \qquad (2)$$

and can be quite variable. The pack-out ratio depends on cucumber size and turgidity but seldom exceeds 0.60. Brine specific gravity is directly related to salt content and may range from 1.019 to 1.078 for weak to strong brines, respectively. The specific gravity of green stock cucumbers varies from 0.958 to 0.982 (Marshall et al., 1973), therefore Δs may vary from 0.037 to 0.12. Cucumber column height may vary from 2 to 4 m (79 to 157 in.) depending on tank depth. These values indicate that Pr may be as small as 435 N/m^2 (9.1 lb/ft^2) or as large as 2825 N/m^2 (58.9 lb/ft^2), over a 6:1 difference. Larger values may exist for fermentations that produce abnormally high gas buildup inside the cucumbers causing them to be more buoyant. Head structures are seldom designed for specific tanks and conditions; they are more likely to be installed by rules of thumb that do not adequately address the wide range of conditions encountered.

One alternative to a rigid head structure is the simple addition of sufficient weight to the top of the cucumber bulk. Discrete objects such as building blocks or sand bags are not attractive since they would incur the same maintenance and storage problems as conventional head structures. However, a liquid ballast would overcome these objectives and is readily available as water or brine.

In order to function as a hold-down or restraining weight and provide isolation from the surroundings, the liquid must be confined to a space above the cucumbers by a rigid, cup-like piston or a flexible envelope. The overlay liquid and fermenting brine must be hydrostatically connected but physically separate. Consider figure 2 which

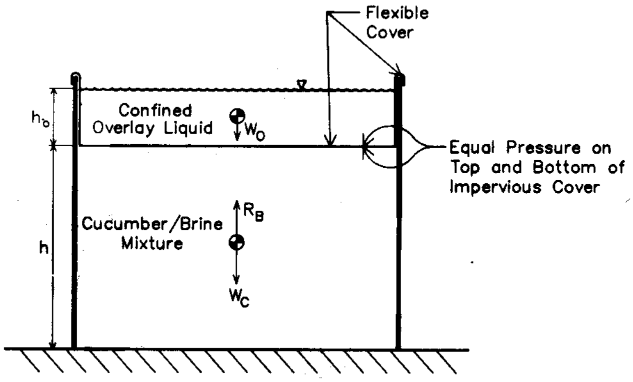

Figure 2–Force relationships for a flexible, impervious, envelope cover, overlay liquid and cucumber-brine mixture.

illustrates the forces involved if the overlay liquid is identical to the brine. Neglecting the weight of the flexible envelope and frictional side effects, the cucumber bulk is in equilibrium when:

$$R_B - Wc - Wo = 0 \qquad (3)$$

where R_B represents the buoyancy force acting on the cucumber bulk pile, Wc the weight of the cucumbers, and Wo the total weight of the overlay brine. Note that:

$$Wo = R_B - Wc \qquad (4)$$

which is equivalent to the total restraining force, R. For a bulk pile of height (h) the required overlay weight per unit area (w_o) is equal to the restraining force per unit area (Pr):

$$w_o = Pr = F\,\rho(\Delta s)\,h. \qquad (5)$$

However,

$$w_o = \rho_o\,(Vol) = \rho_o h_o, \qquad (6)$$

where ρ_o and h_o are the specific weight and depth of the overlay liquid, respectively. Thus, the required overlay depth is:

$$h_o = F\,(\Delta s)\,h\,(\rho/\rho_o). \qquad (7)$$

The extreme case of a 4 m (157 in.) column of least dense cucumbers in most dense brine requires slightly over 0.25 m (10 in.) overlay depth for equilibrium. Since most head structures occupy a similar space, useable tank volume would not be sacrificed.

It is obvious that a rigid envelope, i.e., a cup-like structure separating the overlay liquid from the cucumber-brine mixture could function as a counter weight to buoyancy effects. Notwithstanding the similar practice in the sauerkraut industry, it is somewhat less evident that a flexible membrane confined by the tank walls and cucumber pile would behave in a similar fashion. (The use of flexible covers for restraining cucumbers during fermentation was not discovered in a literature search.) A contained fluid at rest exerts equal pressure in all directions and thus opposite sides of the membrane experience the same total force – overlay liquid weight or the equivalent hydrostatic pressure on the top side to counteract buoyancy and hydrostatic pressure on the bottom side. Conversely, an unconfined overlay liquid (such as would exist for an open mesh or porous cover) would not restrain the cucumbers.

Materials and Methods

The basic concept of using a flexible, impervious membrane and liquid ballast as an alternative head structure was experimentally evaluated in three commercial tanks at a local pickle processor's facilities in 1989/90. Figure 3 illustrates the general features of each tank including the flexible cover, overlay liquid, vent tube, and cucumber-brine mixture. The polyethylene tanks were 2.26 m (90 in.) in diameter, 3.29 m (129.5 in.) deep, and were loaded to a depth of approximately 3 m (118 in.) with cucumbers. Clear polyethylene sheeting 0.114 mm thick (4.5 mils) was employed as the cover material; it was placed over the cucumber pile, draped up and over the tank rim, and secured in place by a nylon cord around the outside of the tanks. Care was taken to allow excess cover material at the cucumber-tank interface to permit expansion/contraction of the tank contents during the brine addition procedure and fermentation. Two layers of sheeting were used for one of the tanks (see Table 1 for variations) as a precaution against accidental punctures. A vent tube for gas escape was installed in the tank center by means of a PVC bulk head fitting with the polyethylene sheeting sandwiched between the compression nuts and appropriate washers.

The overlay liquid to provide the necessary weight was added to each tank. Water was the initial choice (two tanks) since it could be disposed of easily; brine was used in the third tank in an attempt to control algae. The cover must be strong enough to support the overlay liquid on top of the cucumber pile. After placement of the cover and overlay liquid the fermentation brine was added through the vent stack which simultaneously allowed air in the voids between cucumbers to escape. The overlay liquid pressed the cover against the tank walls to form a low pressure seal for anaerobic operation. Brining procedures and fermentations were similar to those described in earlier publications (Etchels et al., 1973; Fleming et al., 1988; Humphries and Fleming, 1988).

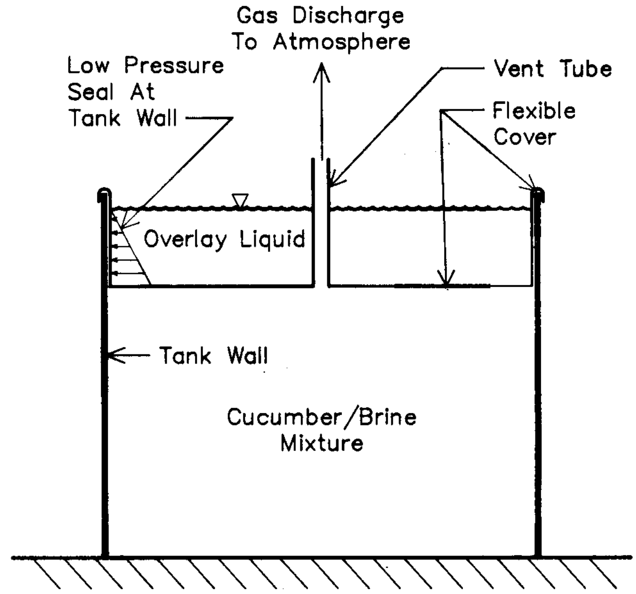

Figure 3–Schematic illustration of flexible cover-overlay liquid system tested in three commercial size tanks.

Results

In all three tanks the flexible cover-overlay liquid system was initially successful in restraining the cucumbers, i.e., in keeping them submerged. In Tank 1 the system functioned as planned throughout the fermentation

TABLE 1. Physical factors associated with 13 000 L capacity, polyethylene tanks for evaluation of alternative head structures

Item	Tank 1	Tank 2	Tank 3
Date brined	9/26/89	9/26/89	10/10/89
Cucumber size*	3B	3B	1B
Flexible cover - 0.114 mm			
(4.5 mil) polyethylene	2 layers	1 layer	1 layer
Overlay liquid	H_2O	H_2O	Brine
Initial brine strength†	40° S	40° S	60° S
Equilibrated brine strength	16° S	18° S	27° S
Cucumber pile surface	Flat	Flat	Peaked‡
Purged	No	Yes	Yes
Vent tube diameter	5.1 cm (2 in.)	5.1 cm (2 in.)	10.2 cm (4 in.)
Overlay depth (tank center)			
Initial	15.5 cm (6 in.)	15.5 cm (6 in.)	17.8 cm (7 in.)
Maximum	28.6 cm (11 1/4 in.)	20.9 cm (8 1/4 in.)	66.0 cm (26 in.)
Minimum	13.3 cm (5 1/4 in.)	5.7 cm (2 1/4 in.)	5.1 cm (2 in.)
Date evaluated	2/23/90	11/7/89	2/23/90

* Diameter: 1B - 1.9 to 2.7 cm (3/4 to 1 1/6 in.)
3B - 4.4 to 5.1 cm (1 3/4 to 2 in.)

† Degrees salometer (°S) is defined as percent saturation with 0 °S being pure water and 100 °S being saturated with salt.

‡ Approximately 15 cm (6 in.) higher at tank center than at tank wall.

and storage period of approximately five months. The depth of the overlay liquid varied due to non-uniform settling of the cucumber bulk and rainfall/evaporation effects. However, the cucumbers were continuously submerged in the brine and the alternative head structure was an unqualified success.

Tank 2 developed a gas bubble under the polyethylene cover within 12 hours as a result of purging, the introduction of N_2 gas through a sparger located near the tank bottom to sweep CO_2 generated by the fermentation from the system (Humphries and Fleming, 1986). Apparently, the entrance to the vent stack (tank center) was lower than the cover at the outer edge of the tank and the purging gas accumulated at the high point. The bubble increased in size to cover about one third of the surface area of the tank top and protruded up through the overlay liquid. After 24 hours, corrections in the system were attempted by bleeding off the trapped gas through a tube installed in the bubble area, cutting off the purging gas, and adding additional overlay liquid to force the cucumber pile lower in the fermenting brine. These measures were successful in re-submerging the entire top surface of the cucumber bulk but the bubble reformed when purging was resumed. Consequently, a layer of cucumbers 10 to 15 cm (4 to 6 in.) deep directly under the bubble eventually spoiled since they were not submerged in brine.

In Tank 3 the cucumber pile was not completely leveled out but retained a uniform conical peak (Table 1) as a residual of the loading operation. The cover was installed to conform to the pile and provided a natural path for gas to escape by funneling it to the vent tube located at the highest point, i.e., the tank center. Overlay liquid depth at the tank center was comparable to the other two tanks but was about 15 cm (6 in.) deeper at the tank wall. The system was successful in maintaining the cucumbers in the fermentation brine and avoided gas bubbles under the cover during the purging process.

The polyethylene covers, even in a single layer, did not fail during the tests. However, in this study precautionary measures to avoid pin-point ruptures or tears were taken. It would not be reasonable to expect similar care under totally commercial conditions. Installation of the covers was not physically difficult but did require manipulating the sheets into position – an awkward endeavor under windy conditions. The flat cover required folds or puckers at the intersection of the cucumber pile and tank wall that were difficult to install in any uniform manner (fig. 4). Stronger, puncture proof, elastic materials, shaped or molded to loosely fit the overlay liquid space are desirable, if not necessary.

Figure 4–Double layer polyethylene alternative head cover after addition of 15.5 cm (6 in.) of water as an overlay liquid.

Brinestock (fermented cucumbers) quality in all three tanks was comparable to that of similar cucumbers brined with conventional head structures with the exception of those in bubble area of Tank 2 as noted above. A slight bleaching of the brinestock was observed on the top surface indicating that the cover and overlay liquid did not effectively block out the sun's rays. Bloater damage levels (sites of excessive CO_2 accumulation inside the cucumbers) was typical in the purged tanks but considerably higher (28%) in the non-purged tank. Brinestock firmness from all three tanks was highly acceptable; color, appearance of cure (i.e., degree of translucency) and other parameters were normal.

Purging, in some instances, produces foam as a consequence of the purging gas bubbling up through the fermentation brine. Tanks 2 and 3 foamed and the foam was forced up the vent tube and overflowed into the overlay liquid. In effect, the purging system operated as a pump to move liquid from underneath the cover to the overlay liquid. It was necessary to add additional brine under the cover to maintain a liquid medium up to the cover. During the storage phase the tank contents were stable and additional brine was not required.

Other considerations must be given to the overlay liquid. Currently, open-top tanks are held outdoors to allow sunlight to strike the brine surface. Ultraviolet rays inhibit growth of film yeasts and mold on the brine surface which, if unchecked, could result in undesirable compounds or eventual spoilage. Algae do not grow because of the high salt concentration and acidity. Water was used as an overlay liquid in two tanks in the present study and after several days, growth of green algae in the overlay liquid was observed. After several weeks, large clumps of algae were observed and an unpleasant odor developed.

Thus, while sunlight inhibits certain types of microbial growth on the surface of acidified brine, it stimulates growth of algae in water. Obviously, this development should be avoided even if the overlay liquid is isolated from the tank contents. Acidification of the overlay liquid may attenuate algae growth, but further studies are in order to ascertain the most practical composition and treatment of the overlay liquid.

Summary

Three commercial size tanks of cucumbers were brined without use of conventional head structures for restraining the cucumbers below the brine surface. A flexible polyethylene cover placed on top of the cucumber pile, draped up and over the tank rim, and weighted down with liquid demonstrated that it could substitute for a rigid head structure. Cucumber buoyancy forces were counteracted by the weight of an overlay liquid confined to the tank top by the cover. Overlay liquid was isolated from the cucumber-brine mixture below the cover. The alternative heading procedure, while lacking in some details of overlay liquid composition and treatment, optimum cover material and

construction, and purging procedures, has potential for converting conventional open-top tanks to closed-top fermentation vessels.

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