Closed-Top Fermentation Tanks for Cucumbers

Ervin G. Humphries, H. P. Fleming
MEMBER
ASAE

ABSTRACT

ADVANTAGES of closed-top anaerobic tanks for processing fresh, pickling type cucumbers into brinestock are discussed and physical attributes related to tank geometry and sealing are examined. Dynamic angle of repose measurements indicate tank tops should have slopes greater than 35 deg to facilitate filling. Static angle of repose measurements suggest that cucumbers could lodge at pile angles up to 73 deg. Manhole openings for movement of materials out of tanks by flotation methods should exceed 37 cm to prevent bridging across the opening. Pipe diameters for free flow of cucumbers and brine should exceed 30 cm. Measurements and observations discussed served as guidelines for installation of a pilot commercial facility.

INTRODUCTION

Large open-top vats or tanks constructed of wood, and more recently fiberglass, are used for commercial fermentation of cucumbers and other vegetables. In the U. S. some 43% (Fleming et al., 1983) of the pickling cucumber crop is brined as a means of rapid bulk storage and temporary preservation thus extending the processing season over the entire year. In recent years brining in open-top tanks has been recognized as contributing to environmental problems; extra salt is added as insurance against spoilage, partially because the tanks are open. This extra salt presents additional disposal problems when the cucumbers are removed from storage and the brine discarded. In addition, growth of aerobic spoilage microorganisms on the brine surface, dilution by rainwater, and contamination by birds, insects, rodents and other foreign agents can occur. The open-top tank is also a deterrent to adoption of new fermentation technology since controlled fermentation utilizing pure cultures (Etchells et al., 1973) is difficult, and perhaps impracticable, in tanks open to the atmosphere. Previous efforts to cover tanks (Fleming et al., 1983) have not been successful because they were not anaerobic; the cover blocked sunlight from the brine resulting in accelerated growth of spoilage organisms.

Article was submitted for publication in August, 1985; reviewed and approved for publication by the Electric Power and Processing Div. of ASAE in November, 1985. Presented as ASAE Paper No. 83-6502.

Paper No. 2 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC.

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 Agricultural Research Service, or does it imply approval to the exclusion of other products that may be suitable.

The authors are: ERVIN G. HUMPHRIES, Professor, Biological and Agricultural Engineering Dept.; and H. P. FLEMING, Professor, USDA-ARS, Food Science, North Carolina State University, Raleigh.

Food scientists have successfully carried out fermentation and subsequent anaerobic long term storage in small containers up to about 20 L (Fleming et al., 1975; Thompson et al., 1979) in the laboratory. Extension of that process to large tanks in typical tankyard environments is the overall objective of a broad interdisciplinary research effort. This paper examined some of the tank geometry constraints and other design features that were considered in the development of a pilot processing facility for fermentation and anaerobic storage in commercial size tanks. Factors associated with the mechanics of moving cucumbers into and out of large closed-top tanks are discussed. The pilot facility consisting of two 4000-L fiberglass tanks and two 34,000-L polyethylene tanks has been installed and operated at Mt. Olive Pickle Co., Mt. Olive, NC; details of its operation and performance have been reported (Fleming et al., 1983).

TANK REQUIREMENTS

Anaerobic fermentation and storage of cucumbers in large closed-to-the-atmosphere tanks involves numerous biological factors and simultaneously must accommodate constraints of the physical system. From an engineering point of view, the tank and its accessories must be a non-leaking vessel with suitable ports or openings through which the cucumbers and materials for brining may be introduced and removed. In addition, provision for changes in volume (due to brine uptake by the cucumbers or expansion/contraction due to temperature changes) and venting of gases produced as a result of fermentation and purging must be made. Provision should also be made for protection against large inadvertent pressure differentials (positive or negative) which can result in structural failure. Furthermore, these operational characteristics must be accomplished without a brine to air interface, i.e. anaerobically.

Tank geometry

Conventional open-top tanks provide ready access via their open tops for rapid bulk loading and unloading methods. Conversion of wood tanks to closed-to-the-atmosphere vessels by the addition of tops was not considered due to variation of dimensions and surface conditions and skewness or out-of-round cross sections. In effect, each tank would require a custom fitted top in order to achieve satisfactory sealing and structural compatibility. Conversion of existing open-top fiberglass tanks to closed-top tanks may be feasible.

To meet the general objectives, cylindrical tanks (no real consideration was ever given to non-cylindrical shapes) with integral dome or cone shaped tops were selected on the basis of availability in fiberglass, polyethylene and other materials. Wood was not considered since it is difficult to control microbial growth on its surface and wooden tanks are difficult to maintain leak free.

Integral top or one-piece tank construction was selected to avoid problems of maintaining a gas tight seal on a large circumference. A typical tank may be thirty to forty thousand liters with a diameter of 3 to 4 m. Even considering that positive pressure within the tank is minimal, maintenance of an effective large diameter seal throughout the tank life involving numerous opening and closing cycles did not appear feasible. Furthermore, movement of the top from the tank for loading/unloading would require hoist equipment (assuming it was not made in sections which would further complicate sealing) due to its size and weight.

Buoyancy Forces

Dome or cone shaped tops were selected over flat (or nearly flat) tops to facilitate loading/unloading operations through manhole size openings and to avoid severe structural deflection of the top due to buoyancy forces. At the beginning of the fermentation process a submerged cucumber requires a restraining or hold down force R given by,

$$R = p\,(\Delta s)\,V$$

where p is the brine weight per unit volume, Δs the difference between brine and cucumber specific weight (brine is more dense) and V the cucumber volume. In a cylindrical tank containing 60% cucumbers and 40% brine by volume, the total restraining force R_t can be represented by,

$$R_t = 0.6\,p\,(\Delta s)\pi\,r^2h$$

where r is the tank radius and h the depth of cucumbers. The specific weight of fresh cucumbers ranges from 0.958 to 0.982 (Marshall et al., 1973) while the specific weight of a typical 10% salt (by weight) brine is 1.076. Under these conditions a 4 m diameter tank with cucumbers 2.5 m deep requires a restraining force on the order of 22,000 N to overcome buoyancy. This force is manifested as a uniformly distributed load of 1750 N/m² acting upward on the tank top. By way of comparison, load carrying capabilities in most residential flooring is seldom designed to exceed this value. Thus a flat top as currently used by the industry requires large timbers similar to floor joists to avoid extreme deflections or bulging that could result in structural damage and loss of sealing. Dome or cone tops must also support the same load but much of the load is tensile as opposed to bending.

Angle of repose

Given the decision to employ integral top tanks with sloping surfaces for the top, the mechanics of moving cucumbers into and out of the tank through a manhole opening in the top of the tank is closely related to the angle of repose for cucumbers. Fig. 1 illustrates the condition that could develop during loading. As the cucumbers are introduced through the top center manhole, they pile up at angle Θ_R, the angle of repose, which depends on their surface and frictional characteristics. If Θ_R is greater than Θ_T, the tank top angle, a void will develop around the perimeter of the tank preventing full use of the tank volume.

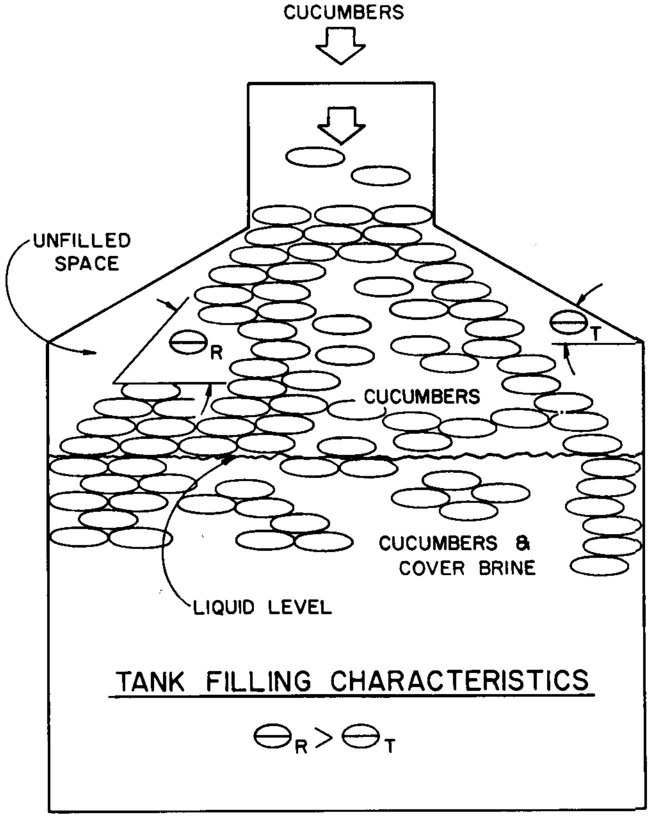

Fig. 1—Angle of repose for cucumbers greater than slope of tank top resulting in unfilled space around the outer perimeter of tank top.

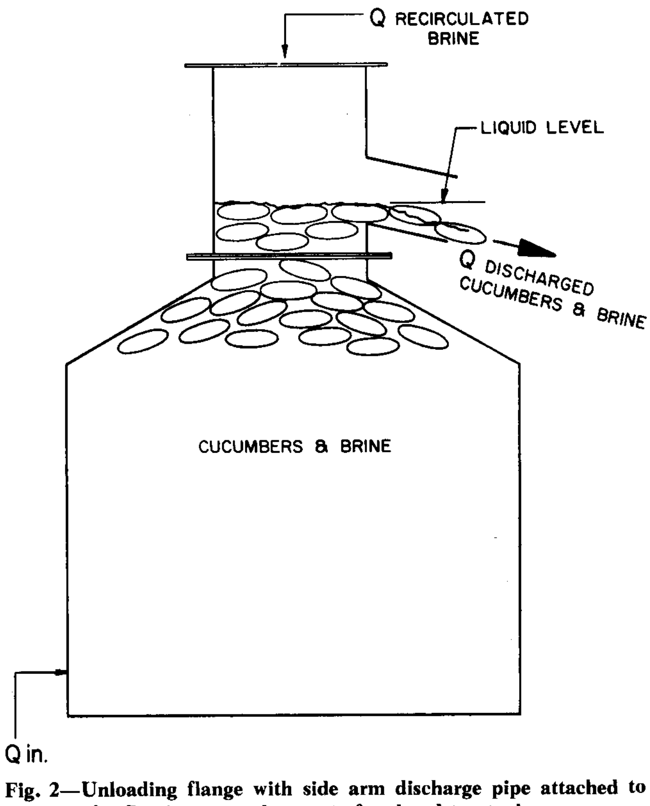

Fig. 2—Unloading flange with side arm discharge pipe attached to tank top for floating cucumbers out of a closed-top tank.

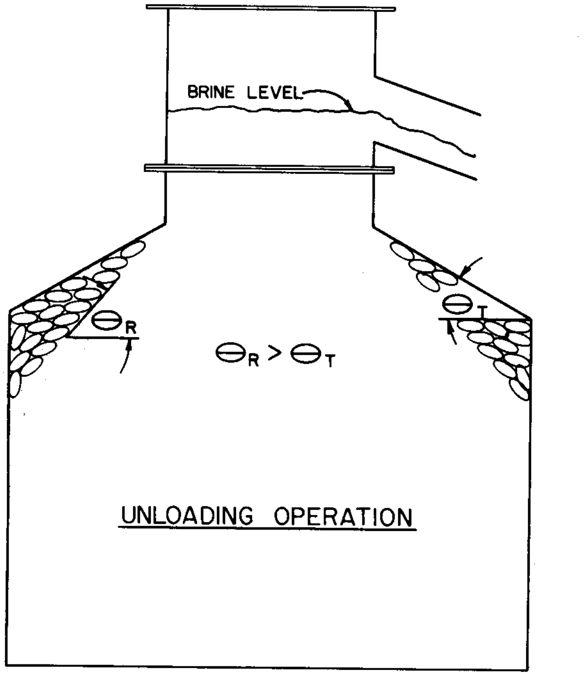

Fig. 3—Angle of repose for cucumbers greater than slope of tank top resulting in possible lodging of cucumbers under top surface of tank during unloading by flotation methods.

Alternatively, if Θ_R is less than Θ_T, the tank can be filled without voids around its top boundaries.

In the unloading operation (Fleming et al., 1983) fermented cucumbers are floated out through the manhole opening and an "unloading flange attachment" by pumping additional brine of slightly greater density into the bottom of the tank (Fig. 2). In this case, the angle of repose of cucumbers floating in brine, i.e. an inverted pile, is the important parameter. If $\Theta_R > \Theta_T$, lodging of cucumbers under the dome or sloping top is possible as illustrated in Fig. 3. For $\Theta_R < \Theta_T$, unloading of the tank is possible without lodging of cucumbers under the tank top.

In order to determine representative values of Θ_R a series of tests was conducted on large (5 cm diameter) green cucumbers over a 2 year period. Since Θ_R is an indication of surface frictional characteristics between cucumbers, a kinetic estimate (analogous to a kinetic or sliding coefficient of friction) was obtained by dropping cucumbers from random orientations at a height of approximately 1.7 m into a large container and measuring appropriate horizontal and vertical dimensions of the resulting conical pile to compute tan Θ_R. A static estimate of Θ_R was obtained by placing a quantity of cucumbers into a cube mounted on a fixed horizontal axis paralleled to four of its sides (Fig. 4). Each edge of the cube was approximately 43 cm and the two faces perpendicular to the axis of rotation were plexiglass to allow observation of the contents. Initially the top surface of the cucumbers was level; the cube (approximately half full of cucumbers) was slowly rotated by means of a hand crank and the angle relative to a horizontal reference at which the cucumbers broke free and tumbled (lost equilibrium) was measured and taken as an indication of the static value of Θ_R.

The results of these measurements are quite variable and are reported in Table 1 for both dynamic and static

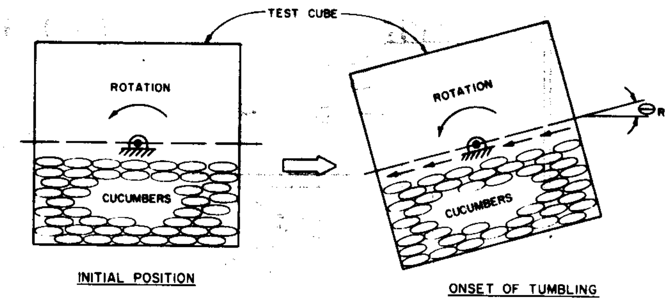

Fig. 4—Rotating cube apparatus to determine static angle of repose or pile at which cucumbers lose equilibrium and tumble.

conditions. As is the case for most materials, the dynamic values are less than static values; the dynamic values are typical (Richey et al., 1961) for agricultural products but static values of tan Θ_R are greater than unity which suggests an interlocking or lodging between individual cucumbers. This could also account for the similarity of observed values of wet and dry cucumbers, i.e. the interlocking effect is of greater magnitude than the classical frictional effect. The dynamic conditions which apply during tank loading suggest that tank top angles should exceed 35 deg. Static values may be more appropriate for unloading and suggest larger tank angles than are normally available from the tank suppliers.

Limiting values for manhole openings

From a materials handling point of view, the most critical aspect of closed top tanks concerns moving cucumbers into and out of the tank. Pumping the cucumbers in a closed system may ultimately be adopted, but at the present it is not widely employed because of equipment limitations. Consequently, gravity type delivery to the tank and flotation methods out of the tank top via the manhole have been instituted.

The flotation method for unloading, (Fleming et al., 1983) requires the installation of an overflow attachment equipped with a side arm exit pipe as illustrated in Fig. 2. Similar devices have been employed in apple handling systems (Tennes et al., 1978) and for other products in

TABLE 1. ANGLE OF REPOSE FOR LARGE DIAMETER (GREATER THAN 5 cm) FRESH CUCUMBERS AS DETERMINED BY DROP TESTS ON A CONICAL PILE (DYNAMIC) AND LOSS OF PILE EQUILIBRIUM (STATIC) METHODS. EACH LINE ENTRY REPRESENTS A DIFFERENT DATE SPANNING A TWO YEAR PERIOD INVOLVING SEVERAL VARIETIES AND GROWING CONDITIONS.

Cucumber surface	No. of observations	Minimum value, deg	Maximum value, deg	Average deg
		Dynamic (calculated)		
Dry	6	24.6	35.5	30.1
Dry	5	13.0	27.4	19.5
Dry	3	31.5	32.0	31.6
Dry	10	19.5	32.1	27.0
Wet	3	16.8	21.9	20.2
Wet	3	33.7	35.0	34.6
Wet	10	13.2	27.9	22.2
		Static (measured)		
Dry	10	55	73	61
Dry	10	45	58	53
Wet	10	52	73	60
Wet	10	62	69	65

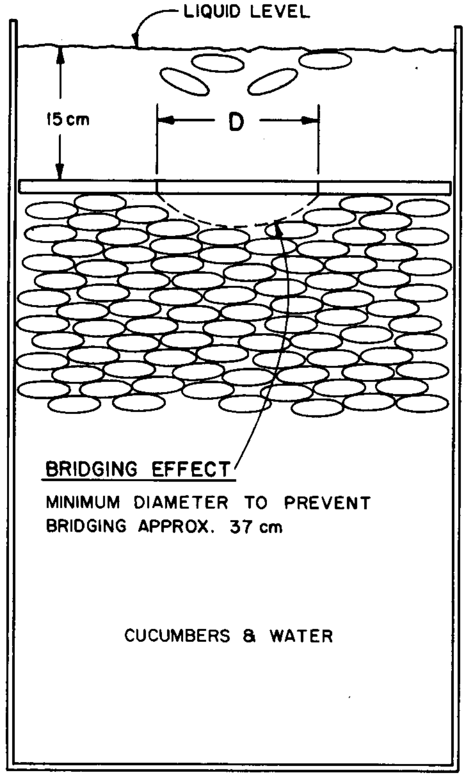

Fig. 5—Test apparatus employed to determine minimum manhole diameter for floating cucumbers out of a closed-top tank.

tank storage. The cover brine and cucumbers overflow the tank as additional brine (usually at 1% greater salt concentration than the pickling brine and therefore more dense) is pumped into the tank bottom causing the mixture to rise in the unloading attachment and subsequently to spill out the exit tube. Mechanical damage to the product is minimal since there are no moving parts in contact with the product as is the case for mechanical or "dipper" conveyors. A gravity flow pipe delivers the mixture to a screening device which separates the cucumbers from the brine. The brine is collected and recirculated to the tank top while the cucumbers are routed to processing.

A critical dimension in the unloading system is at the entrance to the unloading flange. In order to determine the minimum diameter of the manhole and unloading attachment to avoid bridging, a series of tests were conducted with the apparatus shown schematically in Fig. 5. Because the objective was to duplicate the most severe conditions for entry of cucumbers into the flange, the test apparatus consisted of a flat disk (as opposed to a funnel entry) with a circular opening to simulate the test diameter. Additionally, cucumbers (6 cm diameter) larger than those usually brined by industry were used in water which provided less buoyancy or upward lift than brine.

The tank was charged to a depth of 30 to 35 cm with cucumbers, the test disk placed on top and slowly forced down into the tank approximately 15 cm. The cucumbers were also forced down into the tank and tended to rise through the opening. This procedure was repeated 10 times for a 32 cm diameter opening and on each attempt bridging across the opening occurred, i.e. the cucumbers directly beneath the opening did not float out. The test diameter was increased to 37.5 cm and bridging was not observed in 10 trials. These results suggest that opening diameters should be on the order of 37 cm, or larger, and indicate that manhole openings of 60 cm readily available from tank manufacturers should not impede movement of cucumbers in the unloading operation.

Similar tests were conducted with short sections of PVC pipe to establish estimates of the minimum pipe diameter for "full pipe flow" applications. A 20 cm (nominally 8 in.) pipe bridged 8 out of 10 trials while a 30.5 cm (nominally 12 in.) did not bridge in 10 attempts. These results suggest that pipe diameters for full flow pumping should exceed 30 cm, especially for large cucumbers.

SUMMARY

The measurements and observations discussed in this paper served as guidelines for specification and selection of closed-top fermentation tanks employed in a prototype commercial facility (Fleming et al., 1983). Physical attributes related to tank geometry, materials and methods of construction, and size of openings were examined in the context of system requirements. Consideration of buoyancy forces and tank sealing requirements led to selection of one-piece, integral top tanks with sloping tops. Angle of repose measurements for cucumbers indicated that the slope of tank tops should exceed 35 deg to facilitate loading and unloading. Experimental methods were employed to determine minimum diameters for manhole openings and fluming pipes as 37 and 30 cm respectively.

References

1. Etchells, J. L., T. A. Bell, H. P. Fleming, R. E. Kelling, and R. L. Thompson. 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 Science. 3:4-14.
2. Fleming, H. P., J. L. Etchells, R. L. Thompson, and T. A. Bell. 1975. Purging of carbon-dioxide from cucumber brines to reduce bloater damage. J. of Food Science, 40:1304-1310.
3. Fleming, H. P., Ervin G. Humphries, and J. A. Macon. 1983. Progress on development of an anaerobic tank for brining of cucumbers. Pickle Pak Science, 7(1):3-15.
4. Marshall, D. E., J. H. Levin, and D. R. Heldman. 1973. Density sorting of green stock cucumbers for brine stock quality. ASAE Paper No. 73-304, ASAE, St. Joseph, MI 49085-9659.
5. Richey, C. B., Paul Jacobson and C. W. Hall. 1961. Agricultural Engineers Handbook, p. 691. McGraw Hill, NY.
6. Tennes, B. R., C. L. Burton and G. K. Brown. 1978. A bulk handling and storing system for apples. TRANSACTIONS of the ASAE 21(6):1088-1091.
7. Thompson, R. L., H. P. Fleming, and R. J. Monroe. 1979. Effects of storage conditions on firmness of brined cucumbers. J. of Food Science, 44:843-846.