Purging CO_2 from Cucumber Fermentation and Storage Tanks

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ABSTRACT

MEASUREMENTS of CO_2 in the brine of eight closed-top cucumber fermentation tanks were made throughout the active fermentation period. Methods for collecting brine samples from different locations in closed-top tanks and physical variations of their purging system are discussed. When N_2 purging was maintained at the nominal rate of 1.13 m^3/h, excessive CO_2 concentrations were not detected. At reduced purging rates potentially damaging levels of CO_2 did develop and a high incidence of cucumber bloating was observed, particularly in the upper sections of the tanks. The results also confirm that the tendency for bloating is inversely related to depth below the brine surface.

INTRODUCTION

Fermentation and storage of cucumbers in a salt brine is an old and efficient means of temporary preservation for subsequent processing of finished pickle products. Typically, open-top wood, fiberglass, or polyethylene tanks up to 40,000 L capacity are employed for fermentation which may require up to 30 days; the storage period (in the same tank) is usually less than one year but may be several years. Recently, considerable interest has been shown in closed-top tanks (Fleming et al., 1983; Humphries and Fleming, 1986) since they offer a degree of control of the fermentation process, improved sanitary conditions, and a potential reduction in waste disposal volume in comparison to open tanks.

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CO_2 Relationships

In open or closed tanks, CO_2 is produced by metabolic activity of the cucumbers and fermenting organisms which convert sugar to acid. Fermentation in open tanks is primarily the result of naturally occurring microorganisms while added cultures of specific bacteria are employed in closed tanks in an effort to gain control of the fermentation (Fleming et al., 1983). The total amount of CO_2 produced is known to depend on many factors including brine strength (salt concentration), temperature, the type of microorganism(s) responsible for fermentation and the initial sugar and malic acid content of cucumbers (Fleming, 1982, 1974 and 1973; McFeeters et al., 1984). The CO_2 accumulation in the brine results from that produced within, and diffusing from, the cucumbers in addition to that produced by microbial metabolism within the brine. Accumulated production from all sources up to 120 mg of CO_2/100 mL in brine have been reported (Fleming et al., 1973) laboratory studies. Maximum rates of CO_2 production in the brine—based on calculations from the above study—are probably on the order of 25 mg/100 mL per day.

High concentrations of CO_2 in the brine during fermentation have been identified as one of the primary factors in bloater formation (Fleming et al., 1973, 1974 and 1978) i.e. development of hollow cucumbers. Bloater damage results in a loss of yield and quality of fermented pickle products. Diffusion of CO_2 from the brine into the interior of cucumbers at a rate faster than N_2 (the predominate gas in green cucumbers) can diffuse outward has been proposed as the mechanism by which bloating occurs (Fleming and Pharr, 1980). The critical concentration of CO_2 for bloater damage is inversely related to temperature and salt concentration and ranges from 30 to 50% saturation; it may be as low as 25 mg CO_2/100 mL of brine (Fleming, 1979). Hydrostatic pressure varies with tank depth and increases the tolerance level of CO_2 in the brine to near saturation levels (about 100 mg/100 mL at 28 °C and 25 °S) at depths greater than 170 cm (Fleming et al., 1977). On the other hand, increased tank depth increases the buoyancy forces on cucumbers near the top of the tank (restrained below the free liquid surface) and can lead to physical damage (Fleming, 1979; Fleming et al., 1977; Humphries and fleming, 1986).

Purging Systems

Since as much as 120 mg CO_2/100 mL of brine may be produced during fermentation and the critical concentration is, in most instances, less than half this amount, removal of CO_2 from the brine is necessary. Nitrogen purging by means of a sparger and gas lift

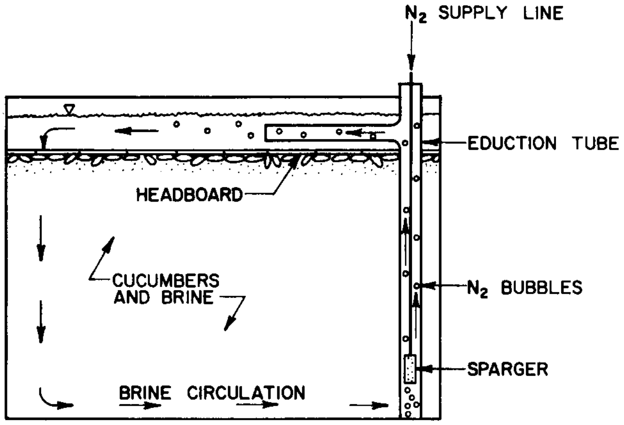

Fig. 1—Typical purging system as employed in open-top tanks consisting of a supply line, sparger (usually 20 μm porosity) and eduction tube operating as a gas lift pump for brine circulation.

pump for circulating the brine has become common in the last 15 years (Costilow et al., 1977; Fleming, 1979; Fleming et al., 1973). Air as a replacement for the more expensive N_2 has been successfully used by some processors (Costilow et al., 1976) but introduces large quantities of 0_2 into an essentially anaerobic process that could stimulate the growth of undesirable aerobic microorganisms (Fleming, 1979).

The purging system (Fig. 1) most common in industry consists of a vertical eduction pipe placed near the tank wall, a gas supply line that releases gas through a sparger unit located near the bottom of the eduction pipe, an elbow or tee at the top of the eduction pipe near the brine surface and a length of horizontal pipe to distribute or propel the circulating brine across the tank top. Operating characteristics of the commonly designated "side arm purger" have been studied (Costilow et al., 1977; McFeeters et al., 1984) in open-top tanks and suggest that brine circulation rates of 4,000 L/h can be attained at gas flow rates of 0.85 m³/h while CO_2 levels in the brine are maintained at 30 mg/100 mL, or less. Variations in the basic configuration of purging systems include those that release gas from a manifold on the tank bottom (Costilow et al., 1977; Fleming, 1979) allowing the purging gas to bubble up through the cucumber-brine mass, center tank units used in connection with a false bottom, and units external to the tank requiring a circulating pump (Costilow et al., 1977). Very little performance data are available for these types of purging units.

The use of closed-top tanks for controlled fermentation (Fleming et al., 1983) has prompted renewed interest in purging systems from the standpoint of design, installation and efficiency, i.e. the amount of CO_2 removed per unit of purging gas used. The operational characteristics of side arm purgers installed in closed-top tanks (Fig. 2) are altered by discharging the eduction pipe gas and brine mixture well below the tank top into cucumbers as opposed to above the cucumbers in open top tanks. In addition, the closed tank conical top funnels all of the CO_2 being removed into a relatively small space at the tank top that may result in abnormally high concentrations of CO_2 (in gas form) at a position in the tank where hydrostatic pressure is lowest and cucumbers are most vulnerable to bouyancy forces. High

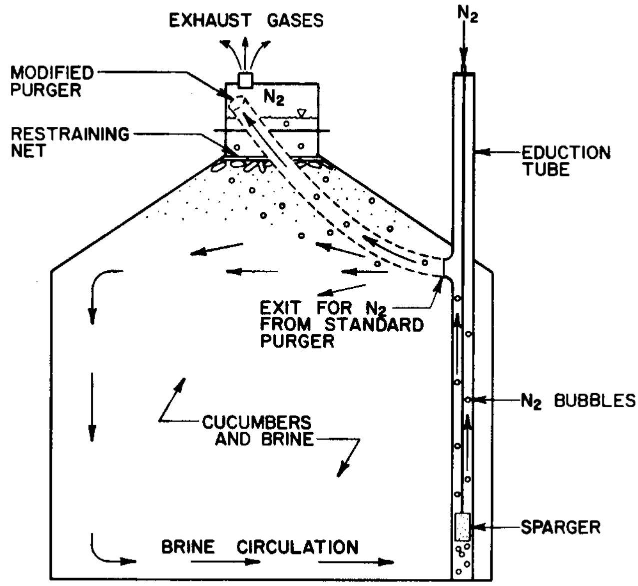

Fig. 2—Purging unit as installed in closed-top tank illustrating standard discharge at the top of tank side-wall and modified discharge (dashed lines) at tank top.

incidence of bloaters in the uppermost sections of closed-top tanks have been observed in several test tanks.

Purging systems have, for the most part, been operated at excessive rates of N_2 that provide acceptable performance but not economy. Rates on the order of 1.133 m³/h (40 SCFH) are routinely employed on large tanks (Fleming et al., 1983). Nitrogen bubbles absorb CO_2 from the brine at a rate that depends on the concentration difference between CO_2 dissolved in the brine and gaseous CO_2 in the bubble. In addition, transport or diffusion of CO_2 from the free brine surface to a gas space at the tank top provides a second pathway for removal of CO_2. In a closed-top tank this pathway is quite small as compared to an open-top tank due to the difference in top surface area. Reaction times for a typical N_2 bubble to absorb the maximum amount of CO_2 have been reported (Segerlind et al., 1978) as considerably less than the time required for it to rise to the tank top. Consequently, the primary pathway for removal is brine to bubble absorption and the smaller liquid-gas interface in a closed-top tank should not impede CO_2 removal.

Objectives

The present study of purging is part of a broad based project that addresses closed-top tank technology and controlled fermentation of cucumbers. In order to optimize the purging function, it will be necessary to consider system design and rate of gas (N_2) flow as related to CO_2 concentration in the brine. The objective of this research is to identify appropriate measurement techniques and establish the operating characteristics of side arm purgers installed in closed-top tanks.

MEASUREMENTS

Size number three (3.8 to 5.1 cm diameter) pickling cucumbers were brined during the spring and summer of 1986, following general procedures for closed-top tanks and controlled fermentation (Fleming et al., 1983).

Fiberglass tanks with a diameter of 3.63 m, overall height of 3.89 m, and 35 deg slope cone top with center manhole, and total capacity of 31,420 L were employed in a series of observational tests involving eight separate tanks. All eight tanks were equipped with a side arm purger constructed from 10.2 cm (4 in.) PVC pipe, Porex gas diffuser, and eduction pipe opening at the top of the cylinderical tank wall (Fig. 2). The purging unit in two tanks was modified by attaching a flexible line (10.2 cm diameter) to the education discharge opening and terminating above the cucumbers and brine surface in the manhole neck of the tank (Fig. 2). Five tanks were purged with N_2 at the nominal rate of 1.133 m^3/h, two tanks were purged at the nominal rate for one day and then 1/4 the nominal rate for the remainder of the tests, and one tank was purged at 1/20 the nominal rate for the entire test. Flow rates were determined by float-tapered tube type flow meters installed in the supply line to each tank. Rigid manhole covers with 5 cm diameter, clear PVC vent stacks 122 cm long and fittings for 1 cm (3/8 in.) flexible Tygon tubing that served as brine sampling lines were employed on four tanks. The other four tanks were left open at the manhole.

Brine samples were taken from two center-line positions in each tank, approximately 60 cm (in the cone area) and 240 cm (in the bottom half) below the tank top on a daily basis during the most critical fermentation period. Additionally, five samples from other positions along the tank edges and bottom were collected for the first test (Tank 1); the top brine surface was sampled for the last four tanks. Flexible Tygon tubing employed in Tank 1 tended to collapse and was replaced by stainless steel tubing (1 cm diameter) for subsequent tanks. The tubes were closed at their bottom end and perforated along a 12 cm section near the bottom end to allow brine to enter from the corresponding tank position. Flexible tubing was attached to the top end of the stainless steel tubing (above the cucumbers) and led outside the tank through the manhole or manhole cover to allow the respective samples to be siphoned from the tank. The brine samples were removed from the sample tubes by hypodermic syringe and analyzed for CO_2 following previously developed techniques in widespread use (Fleming et al., 1974).

In the four tanks equipped with manhole covers and vent stacks, an isolated gas headspace above the brine was accessible via ports in the manhole cover and/or vent stack. Samples of the headspace gas were analyzed for CO_2 by a portable Bacharach FYRITE® gas analyzer by inserting the aspirator tube of the analyzer through a port. Care was taken to draw the gas sample from a position free of foam produced as a result of purging. The analyzer was equipped to read 0 to 20% CO_2 (by volume) and could be read to the nearest 1%.

An indication of quality of the fermented cucumbers was obtained through a subjective rating process for lens, honeycomb and balloon bloaters. These observations were used to calculate a bloater index (Etchells et al., 1974) that is employed in the industry as an indication of quality. Samples, of 50 cucumbers each, were drawn from the surface, cone area and central tank area after the fermentation process was completed and essentially storage of the tank was underway. Surface samples were removed by hand. The two interior tank samples were

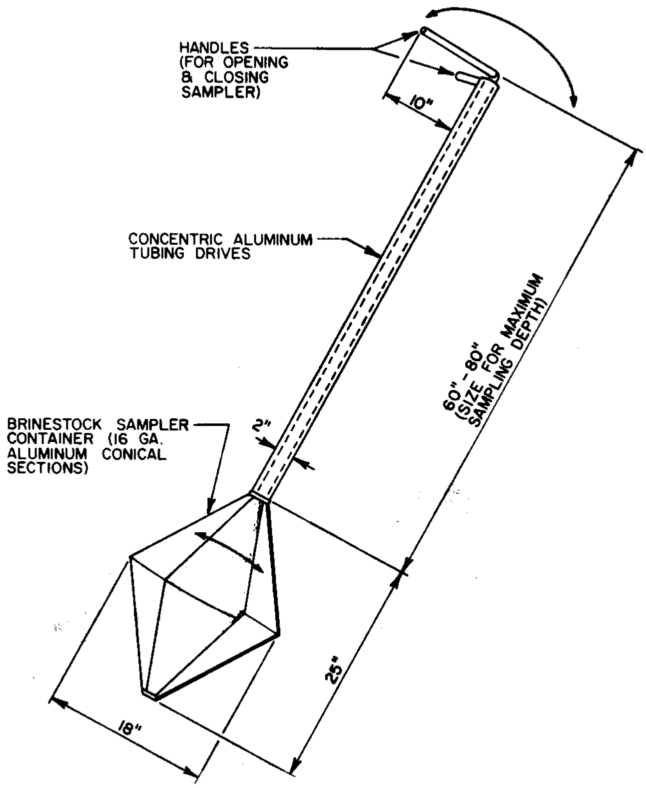

Fig. 3—Schematic of brinestock sampling device for drawing samples of approximately 25 kg from specific tank depths.

taken by a brinestock sampling probe that could be inserted to the proper depth, opened to capture a sample of approximately 25 kg, closed, and then withdrawn. The sampler and its operation are illustrated in Fig. 3.

RESULTS AND DISCUSSION

Brine CO_2 Concentration

Measurement of CO_2 concentration in the brine at seven locations in Tank I over a 240 h period indicate highly variable, but not uncommon, changes (Fig. 4). The sample tube for location #1 (Fig. 4) was blocked during the test process and subsequent samples were not possible. Three other missing data points were also due to blockage of the Tygon sample tubes from shifting or heaving of the cucumber bulk during fermentation; later tests on Tanks II to VIII were run with stainless steel tubes that did not collapse.

The largest observed CO_2 concentration difference between any two locations occurred 24 h into the test when the middle of the tank (location 2) indicated 16 mg CO_2/100 mL brine and the top sidewall opposite the purger discharge (location 7) indicated 39 mg/100 mL. Since purging is the mechanism by which CO_2 is removed from brine, the largest difference was expected between the purger intake (location 4) and discharge (location 5). However, these two positions tracked relatively close together. With three exceptions, all locations increased/decreased during the same time period, albeit at different rates, suggesting adequate circulation or mixing of the brine throughout the tank.

The CO_2 levels were well within the range of acceptable values for the specific test conditions; the highest value of 39 mg/100 mL was less than 50% of

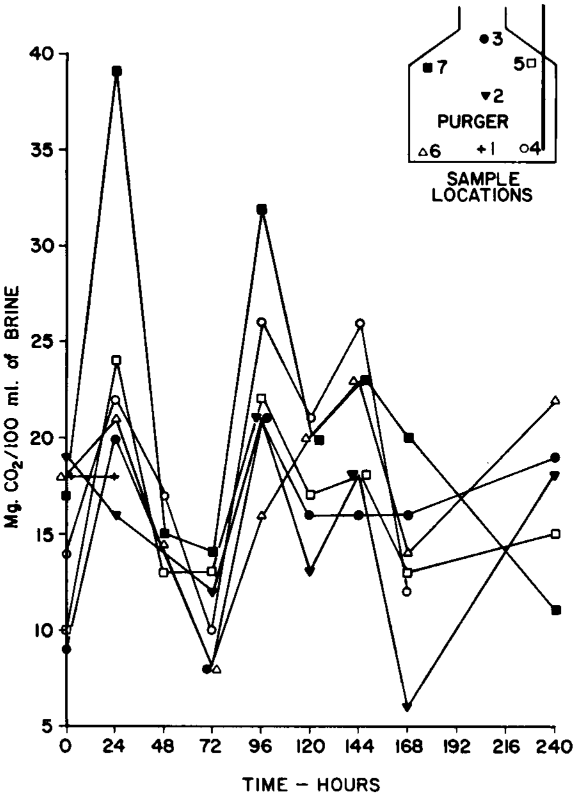

Fig. 4—Concentration of CO_2 dissolved in the brine at different locations in Tank 1 during fermentation.

saturation suggested as a guideline by a previous investigation (Fleming, 1979). At the 1.133 m^3/h (40 SCFH) N_2 purging rate, CO_2 in the exhaust gases from the tank ranged between 1 and 3% (by volume) as measured by the Bacharach FYRITE® analyzer, suggesting that excess N_2 was being used. Perhaps most important, excessive levels of CO_2 were not detected in the cone section (location 3) of the tank.

As a result of our experiences with Tank I and the effort required in collecting and anlyzing brine samples, only two positions, the tank mid-section (location 2) and cone section (location 3) were sampled in Tanks II to IV. Subsequently, in Tanks V to VIII a brine sample from the top surface was collected and analyzed. The results of these measurements are reported in Table 1; the corresponding positions for Tank I are also included for ease of comparison.

The effect of the purging rate is quite evident in the series of measurements for Tanks II, III and IV. Tanks II and IV were essentially replications at a flow rate of 1.133 m^3/h while Tank III was operated at 1/20 of that value in an attempt to overload the system. The CO_2 concentrations responded as expected in that the two locations in each tank tended to track together as observed in Tank I. Tanks II and IV indicate a decreasing concentration, especially during the latter stages of fermentation, suggesting that the purging system removed CO_2 faster than it was generated. However, Tank III, at the lower purging rate, indicated increasing levels of CO_2, attaining potentially damaging concentrations of 71 and 62 mg/100 mL for locations 2

TABLE 1. CARBON DIOXIDE CONCENTRATION IN BRINE BY LOCATION IN TANK AND DAYS OF FERMENTATION EXPRESSED AS mg CO_2/100 mL BRINE

Tank & date brined	Location in tank	Days of fermentation 0	1	2	3	4	5	6	7	8	9	10	Purge rate & system†
Tank I	Mid-tank	19	16	—*	12	21	13	18	6			18	N
5/19/86	Cone section	9	20	—	8	21	16	16	16			19	S
Tank II	Mid-tank	24	29	32	26	25	27		17			17	N
6/24/86	Cone section	22	30	32	26	—	34		14			16	S
Tank III	Mid-tank	38	52	47	47	40		71			66		N/20
6/25/86	Cone section	24	60	48	44	42		62			69		S
Tank IV	Mid-tank	35	34	35	34		32			22			N
6/26/86	Cone section	31	38	38	40		37			18			S
Tank V	Mid-tank	13	36	46	24	30		25		36	36	32	N,first day
7/1/86	Cone section	12	32	40	34	25		38		37	29	27	then N/4
	Top surface	22	31	47	34	27		—		38	28	34	S
Tank VI	Mid-tank	23	27	33	26	45		25		22	23	37	N,first day
7/1/86	Cone section	21	29	33	32	42		28		18	21	25	then N/4
	Top surface	22	28	34	21	30		—		17	16	19	M
Tank VII	Mid-tank	31	—	32	31		31		20		20		N
7/9/86	Cone section	23	28	30	29		—		23		14		
	Top surface	25	29	28	—		—		—		—		S
Tank VIII	Mid-tank	50	35	23	30		22		25			15	N
7/9/86	Cone section	48	32	37	25		20		21			12	
	Top surface	—	25	27	—		—		21			—	M

*Dash (—) indicates data not available due to blocked sample tube or faulty analysis, blank spaces indicate no attempt to sample.
†N denotes a purge rate of 1.133 m^3/h (40 SCFH), S denotes side arm purging unit and M denotes modification to side arm unit to discharge at the tank top.

and 3, respectively after 6 days. Furthermore, measurement of CO_2 in the headspace/vent stack gases indicated that at the lower purging rate, CO_2 exceeded 20% (by volume) while at the higher rates in Tank II and IV, it never exceeded 12% and was in the 2 to 3% range after the first day.

Tanks V and VI were operated at a purging rate of 1.133 m^3/h for the first 24 h and then reduced to one fourth of that value for the remainder of the tests. The purging unit for Tank VI was modified (Fig. 2) to discharge at the tank top above the brine surface eliminating contact between the purging gases and cucumbers. An additional brine sampling position was established at the surface of both tanks.

The CO_2 concentrations observed were similar in magnitude and behavior to those for previous tanks with the mid-tank location reaching a maximum of 45 and 46 mg/100 mL in Tank V and VI respectively. The surface values of CO_2 concentration for Tank VI did not show a marked decrease over those for locations 2 and 3 as was expected since the discharge from the purging unit should register low CO_2 concentrations. Measurements of gaseous CO_2 in the headspace/vent stack were not attempted since the manhole covers were omitted to allow the surface measurements.

Tanks VII and VIII were also operated as standard and modified purging units respectively, but were purged at the normal rate of 1.133 m^3/h throughout the fermentation. Again, there were no striking dissimilarities with regard to CO_2 concentration; initial values for Tank VIII were higher than for previous tanks but were in an acceptable range after the first day. Surface measurements did not indicate an advantage for either purging system.

Bloater Indexes

Bloater indexes for Tank I were determined four months after brining; Tanks II to VIII were rated 6 to 8 weeks after brining. Results for the mid-tank, cone section, and top surface are reported in Table 2 along with purging rate and configuration. Bloater indexes below a value of 5 are typical in a satisfactory purging operation; by this criterion, the mid-tank indexes representing the bulk (84% of tank volume) of cucumbers in each tank were quite satisfactory with the exception of Tank III. The effects of an extremely low purging rate and high CO_2 concentrations are obvious for the mid-tank and to a lesser extent for the other two locations of Tank III. Only two (Tank V and VII) of the remaining seven tanks had unsatisfactory bloater indexes for the cone section (15% of tank volume). Since both were equipped with side arm purgers, one might-suspect the reduced purging rate for Tank V but an apparent explanation is not available for Tank VII.

Bloater indexes for the top surface of all tanks were relatively high and quite unsatisfactory. This sample represents only about 1% of the tank contents but the presence of a high bloater content is an impediment to subsequent processing operations. Modification of the purging unit (Tanks VI and VIII) to discharge above the cucumbers in the tank top apparently did not alleviate the problem. Operation at the higher purge rate did not significantly reduce the surface bloater index as the lowest value (13.2) was recorded for Tank III, operated at the lowest purge rate.

Additionally, there does not appear to be a relationship between the bloater index for the three locations within each tank. The correlation coefficient between positions 2 and 3 was only 0.39, between 2 and the surface −0.47, and between 3 and the surface 0.05. On the other hand, the average bloater index by position for all eight tanks suggests a definite inverse relationship with depth below the brine surface. This response has been observed in industry with open top tanks and agrees with a previous study (Fleming et al., 1977) of the effects of brine depth or hydrostatic pressure on bloating.

CONCLUSIONS AND RECOMMENDATIONS

Individually, two of the eight tanks provide important information. Tank I indicates that closed-top tanks operated with a side-arm purging unit circulates and

TABLE 2. BLOATER INDEX* BY TANK LOCATION

Tank	Mid-tank	Tank location cone section	Top surface	Purge rate†	Purge system‡
I	0.1	0.7	21.0	N	S
II	1.1	0.2	24.9	N	S
III	8.6	15.5	13.2	N/20	S
IV	2.1	4.9	22.7	N	S
V	0.6	17.6	54.5	N, first day then N/4	S
VI	1.2	3.9	36.9	N, first day then N/4	M
VII	1.1	19.4	15.8	N	S
VIII	0	2.5	31.6	N	M
Mean value	1.85	8.09	27.5		
Std. dev.	1.80	8.01	13.3		

*Based on a rating procedure as described in reference 3.
†N denotes a purge rate of 1.133 m^3/h (40 SCFH).
‡S denotes dide arm purging unit, M denotes modification to side arm unit to discharge at the tank top.

mixes the brine throughout the tank and that multiple brine samples may not be necessary. Tank III, operated at an extremely low purging rate verifies that purging is beneficial and that purging rates can be too low.

Collectively, the eight tanks for which a variety of conditions and operating techniques were imposed, indicate a serious bloater problem at the top of the tank involving approximately 1% of the tank volume. This may be due to low hydrostatic pressure, high buoyancy forces or some other unknown factor(s). Excessive concentrations of CO_2 in the brine at the top of the tank were not detected in the four tanks sampled and are not thought to be the cause of the high bloater indexes. Modification of the purging units to discharge the brine and gas mixture above the cucumbers apparently had little effect on CO_2 concentration or bloater incidence at the tank top.

Within the interior of the tank, CO_2 concentrations were limited to safe levels and bloater indexes were, for the most part, acceptable. Data from Tanks V and VI offer evidence that the purging rate may be reduced without affecting the main contents of the tank. Limited measurements of CO_2 concentration in the exhaust gases indicated relatively low levels, especially at the higher purging rates and may be a means of monitoring purging efficiency. Data from four tanks also supports a reduction in N_2 purging rates.

Factors influencing purging efficiency, especially the rate of CO_2 transfer, have not been identified in terms of process variables. In future investigations it is also recommended that hydrostatic pressure be included as a variable. In terms of the amount of N_2 required to prevent bloater damage, it may be more efficient to recirculate the exhaust gases through the tank or to circulate the brine through an external tank scrubber. Development of transducers to detect CO_2 concentration and adjust the purging mechanism accordingly would fill a necessary requirement for automation of the purging system.

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