Project Number: 83-Q7

Proceedings also included; separated by yellow paper divider

PRELIMINARY RESEARCH REPORT

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ECONOMICS OF LOW-OXYGEN GENERATED ATMOSPHERES FOR ALMONDS

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Cost Estimates for Insect Control in Bulk-Stored Almonds Using Methyl Bromide and Phosphine Fumigations and a Generated Low-Oxygen Atmosphere

It is important in developing a new method of insect control to evaluate its economic cost and compare it with costs of existing control methods. To do this, data was elicited on current control methods and their associated costs. Data for this part of the analysis were collected for the last half of 1983. Much of the cost data for current fumigations were provided by the California Almond Growers Exchange. In addition, actual field tests with a 10,000 ft^3 capacity inert gas generator (Gas Atmospheres Inc.) used on silos capable of handling 500 tons of almonds provided information on the biological and economic feasibility of the low-oxygen technique.

In a cost-study of this type, certain assumptions were considered critical and although unsubstantiated, were included in the analysis. These assumptions were:

1. A maximum maintenance rate of 500 SCFH for the low-oxygen atmosphere. Prior research with raisins and almonds has shown this rate was attainable. We believe the almond storage silos can be made this air-tight.
2. Labor required for oxygenless atmosphere application is 4 hours per day. If the silos are permanently sealed and the system fully automated, labor of 4 hours or less should be more than adequate.

The cost of oxygenless atmospheres will vary greatly depending on the application, location, energy sources, and labor costs. It is a technology that is basically substituting capital for labor. The problem becomes one of allocating the capital cost over as many tons of product as possible in order to bring the cost per ton down to economically feasible levels. With respect to the 10,000 SCFH oxygenless generator, material costs are approximately $7.73/hr but the total capital outlay for this installation is roughly estimated at $139,000. It takes many tons of almonds to bring that cost down to a reasonable, economical level. Of course there are much smaller gas generators requiring less capital and whose operating expenses are much less. Matching the machine to the storage is clearly critical in this type of analysis.

Based on our analysis, it would appear that an oxygenless atmosphere is both biologically and economically feasible for application in a facility similar to that of the California Almond Growers Exchange.

In this application, the silos are used as a reservoir for the processing plant. Raw product is assumed to remain no longer than 30 days. The silos are purged with an oxygenless atmosphere for 24 hours with 7000 SCFH and maintained at 500 SCFH for 144 hours. This means that the entire process as we have structured the example will require a week to complete. It should be noted however that feeding activity of insects stops very early in the process and only under the most difficult of circumstances would 7 days be required for the process.

The cost analysis assumes one new silo is purged each day thus 180 silos over the 6-month season are fumigated. Assuming 500 tons per silo, this would mean 90,000 tons would be fumigated with oxygenless atmospheres. If 90,000 tons could be pushed through the system, this would result in an estimated cost of $.84/ton. However, this cost increases to $1.51/ton when only 50,000 tons are processed. When heat is recovered as a by-product of the combustion process, the cost drops to $.63/ton for 90,000 tons and $1.13/ton for 50,000 tons. If hot water or steam is utilized at the processing plant it is reasonable to assume 80% of the heat can be reclaimed and utilized, thus reducing the cost of operation.

The cost of fumigation using magnesium phosphide and methyl bromide was determined using 250 fumigations per year. The costs varied from $1.79/ton for 50,000 tons to $.99/ton for 90,000 tons for magnesium phosphide. For methyl bromide, the costs varied from $2.83/ton for 50,000 ton to $1.57/ton for 90,000 tons. These costs are summarized and graphically depicted in Figure 1. The calculations are presented in Tables 1-4 and Table 5 also summarizes the results. As we have calculated the costs, it is our tentative conclusion that methyl bromide is the more expensive alternative. For certain applications it would appear the almond industry has a suitable alternative to methyl bromide.

Table 1. Cost of Treating Stored Almonds with Generated Oxygen Atmosphere Without Heat Recovery[1/]

Capital Equipment	Initial Cost	Years Life	Annual Cost	Maintenance	Total	
Inert Gas Generator[2/]	$60,000					
Sequencing Flow analyzer	4,000					
4-6 point recorders alarms	12,000					
Turndown valves	4,000					
Cooling tower	5,000					
Plumbing Sealing 24 silos[3/]	48,000					
Tunnel Fan	6,000					
	$139,000	15	$9,267	$6,950	$16,217	
Interest on Investment (12%)					16,680	
Total Annual Cost Capital Equipment						$32,897
Labor - Direct Cost						
4 hours/day @ $11.00/hour						$7,920
Materials						
Natural Gas 1160 SCFH @ $.60873/Therm					$30,505	
Electricity 5.7 KWH @ $.07/KWH					1,724	
Electricity Cooling Tower 1.4 KWH @ $.07/KWH					417	
Electricity Fan 6.3 KWH @ $.07/KWH					1,905	
Total Materials						$34,551
Total Cost of Operation 180 days without heat recovery						$75,368

Table 1: (Cont'd)

Cost per delivered ton	50,000 tons	1.5074 per ton
	60,000	1.2561
	70,000	1.0767
	80,000	.9421
	90,000	8374

1/ 24 Silos - 180 day season.
2/ 10,000 SCFH, 7,000 SCFH for 24 hours to purge, 500 SCFH for 144 hours for maintenance.
3/ Based on limited experience.

Table 2. Cost of Treating Stored Almonds With Generated Oxygenless Atmosphere With Heat Recovery[1/]

Capital Equipment	Initial Cost	Years Life	Annual Cost	Maintenance	Total	
Inert Gas Generator[2/]	$60,000					
Heat recovery system	11,000					
Sequencing flow analyzer	4,000					
4-6 point recorders alarms	12,000					
Turndown valves	4,000					
Plumbing, Sealing 24 silos[3/]	48,000					
Plumbing heat recovery[4/]	20,000					
Tunnel Fan 10 H.P.	6,000					
	$165,000	15	$11,000	$8,250	$19,250	
Interest on Investment (12%)					19,800	
Total Annual Cost Capital Equipment						$39,050
Labor - Direct Cost						
4 hours/day at $11.00/hr						$ 7,920
Materials						
Natural Gas 1160 SCFH $.60873/Therm	$30,504.68 @ 80% Recovery				$ 6,101	
Electricity 5.7 KWH @ .07/KWH					1,724	
Electricity Fan 6.3 KWH @ .07/KWH					1,905	
Total Materials						$ 9,730
Total Cost of operation 180 days with heat recovery						$56,700

Table 2. (Cont'd).

Cost per delivered ton	50,000 tons	$1.1340 per ton
	60,000	.9450
	70,000	.8100
	80,000	.7088
	90,000	.6300

1/ 24 Silos - 180 day season.
2/ 10,000 SCFH, 7,000 SCFH for 24 hours to purge, 500 SCFH for 144 hours for maintenance.
3/ Based on limited experience.
4/ Depends on location.

Table 3. Cost of Treating Stored Almonds With Magnesium Phosphide[1/]

Capital Equipment	Initial Cost	Years Life	Actual Cost	Maintenance	Total	
Fans (3)	$15,000	10	$1,500	$3,000	$4,500	
Special Storage Building	10,000	20	500		500	
Safety Equipment						
Self Contained Breathing	5,000	5	1,000	500	1,500	
Face shields			1,000		1,000	
Bottled Air			2,000		2,000	
	$30,000					$9,500
80% allocated to silos; 20% to flat storage					7,600	
Interest on Investment (12%)					3,600	
Total Annual Cost Capital Equipment						$11,200
Labor-Direct Cost						
Sealing, Application, Monitoring, Aeration 2 persons/shift for 3 shifts, 180 days @ $11.00/hr (including benefits) $95,040 80% Silos $76,032. Magnesium Phosphide 50% of Methyl Bromide					$38,016	
Training 4.5 hours/person/season 8 persons = 36 hours @ $11.00/hr = $396/season @ 80%					317	
Total Labor						$38,333
Materials						
Magnesium Phosphide - Two strips @ $45.00 each 250 fumigations per year at $90/fumigation					$22,500	
Tape, polyethylene, propane $10.00/silo					2,500	

1/ 24 Silos - 180 day season

Table 3: (Cont'd)

Electricity

Venting Silo	5 H.P.	12 hrs/day	3.2 KWH	$ 484	
Recirculation Silo	5 H.P.	23 hrs/day	3.2 KWH	927	
Venting Tunnel	10 H.P.	24 hrs/day	6.3 KWH	1,905	
Assume 85% efficiency $.07 KWH					
Total electricity					$3,316

Residual Samples

Sample	$35.00/silo	8,750	
Labor	$11.00/silo	2,750	
Total Sampling			$11,500
Total Cost Magnesium Phosphide Fumigation			$89,349

Cost per delivered ton	50,000 tons	$1.7870
	60,000	1.4892
	70,000	1.2764
	80,000	1.1169
	90,000	.9928

Table 4. Cost of Treating Stored Almonds With Methyl Bromide

Capital Equipment	Initial Cost	Years Life	Annual Cost	Maintenance	Total	
Cart	$ 3,000	10	$ 300	$ 300	$ 600	
Fans (3)	15,000	10	1,500	3,000	4,500	
Evaporator-Exchange	500	5	100	100	200	
Special Storage Building	10,000	20	500		500	
Safety Equipment						
Self Contained Breathing	5,000	5	1,000	500	1,500	
Face shields			1,000		1,000	
Bottled Air			2,000		2,000	
	$33,500				$10,300	
80% allocated to silos; 20% to flat storage					8,240	
Interest on Investment (12%)					4,020	
Total Annual Cost Capital Equipment						$12,260
Labor-Direct Cost						
Sealing, Application, Monitoring, Aeration 2 persons/shift for 3 shifts, 180 days @ $11.00/hr (including benefits) 80% Silos $95,040					$76,032	
Training 4.5 hours/person/season 8 persons = 36 hours @ $11.00/hr = $396/season @ 80%					317	
Total Labor						$76,349
Materials						
Methyl Bromide 3.5 lbs/1000 cubic feet 45,000 cubic feet per silo = 157.5 lbs/silo 250 fumigations per year at $.90/lb					$35,438	
Tape, polyethylene, propane $10.00/silo					2,500	
						$37,938

1/ 24 Silos - 180 season.

Table 4: (Cont'd)

Electricity

Venting Silo	5 H.P.	12 hrs/day	3.2 KWH	$ 484	
Recirculation Silo	5 H.P.	23 hrs/day	3.2 KWH	927	
Venting Tunnel	10 H.P.	24 hrs/day	6.3 KWH	1,905	
Assume 85% efficiency $.07 KWH					
Total Electricity					$3,316

Residual Samples

Sample	$35.00/silo	8,750	
Labor	$11.00/silo	2,750	
Total Sampling			$11,500

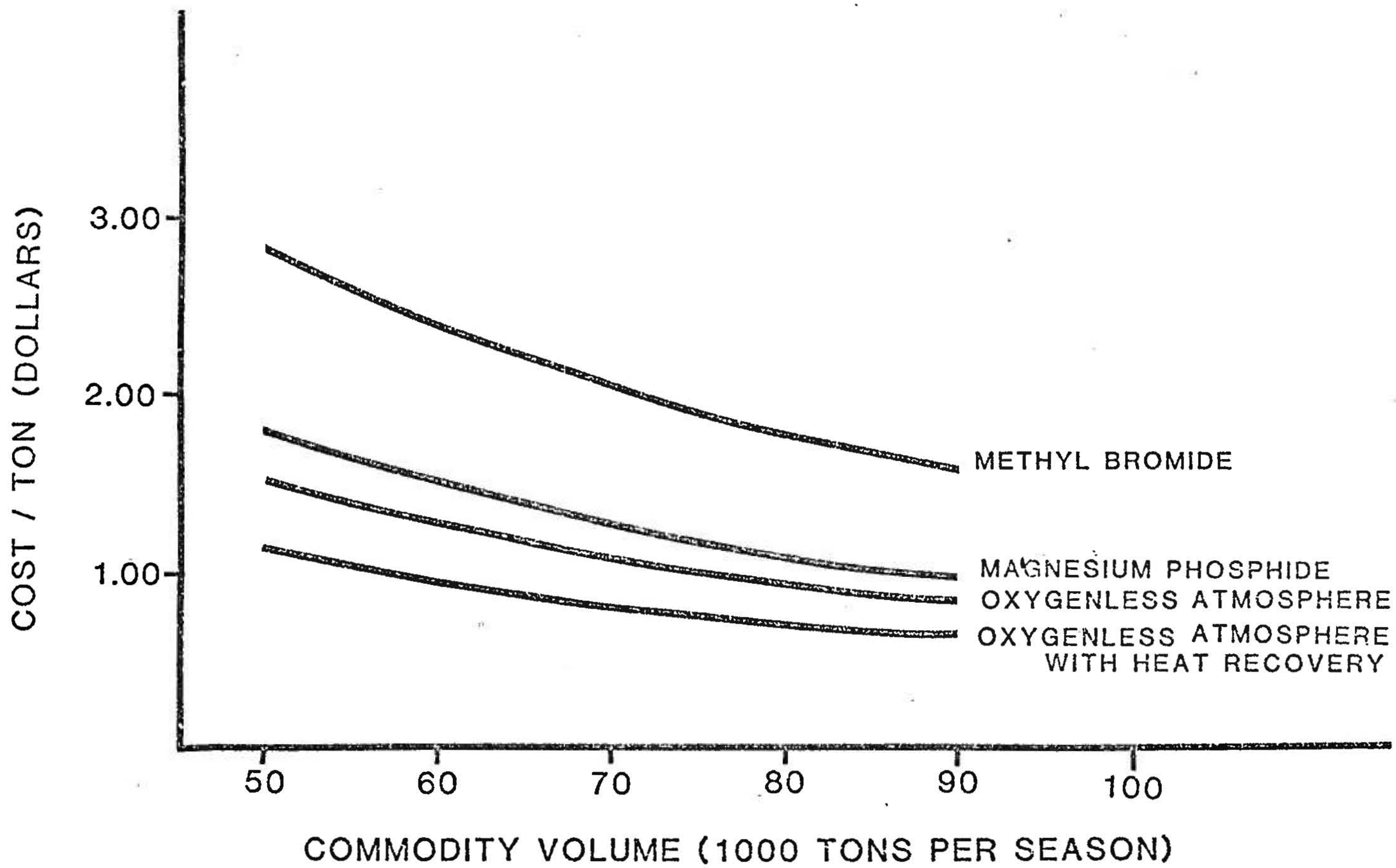
Total Cost Methyl Bromide Fumigation $141,303

Cost per delivered ton	50,000 tons	$2.8261
	60,000	2.3551
	70,000	2.0186
	80,000	1.7663
	90,000	1.5700

Table 5. Cost of Treating Various Volumes of Almonds in Silos With Fumigant Alternative Methods

Actual Tonnage	Methyl Bromide	Magnesium Phosphide	Oxygenless	Oxygenless Heat Recovery
50,000	$2.83	$1.79	$1.51	$1.13
60,000	2.36	1.49	1.26	.95
70,000	2.02	1.28	1.08	.81
80,000	1.77	1.12	.94	.71
90,000	1.57	.99	.84	.63

FIG.1: COST OF TREATING VARIOUS VOLUMES OF ALMONDS IN SILOS WITH FUMIGANTS AND A GENERATED LOW OXYGEN ATMOSPHERE



Another part of this study looked at the cost of oxygenless atmospheres for the more traditional "flat storage." Unfortunately, for various reasons, an actual test was not completed satisfactorily to provide sufficient data to give a cost comparison. However, given the experience of previous work on almond silos, raisins storage, manufacturer's data, and the information provided by the Washington State apple storage industry's experience with controlled atmospheres, budgets were constructed for various tonnages. These costs should be used cautiously since they are engineered and not in fact verified by actual on-site data. It should also be kept in mind that storing almonds in an oxygenless atmosphere, while it may have many advantages such as reduced fire hazzard and preserving quality, also may require packers to rethink their method of operation. Under the oxygenless atmospheres system packers may lose some of their flexibility when compared with methyl bromide treatments. In particular, once a storage area is sealed, its near oxygenless atmosphere should remain until the seal is broken and the product should be used presumably within 30 days or before reinfestation can occur. Repeated resealing and repurging would be more expensive.

Critical to this analysis and technology is the assumption concerning a sealed, reasonably airtight structure. Whether using oxygenless atmospheres, phosphine, carbon dioxide, or the newly recommended low levels of methyl bromide for reduced residues on the almonds, it is vital to make certain the storage facility is well sealed. The cost of sealing was not accounted for in this specific analysis but it could be substantial regardless of the fumigation technique used.

The following assumptions serve as the basis for this part of the analysis:

1. The capital cost for the generator without heat recovery is,

10,000 SCFH Gas Generator	$60,000
Sequencing Flow Analyzer	4,000
1-6 point recorder alarm	2,000
4 Turndown valves	1,000
Cooling Tower (no heat recovery)	5,000
Plumbing and Miscellaneous	3,000
	$75,000

2. Annual maintenance and servicing is equal to 5 percent of the capital.

3. Depreciation is based on an expected useful life of 15 years and interest on investment calculated at 12 percent.

4. Since it is fully automated, the oxygenless generator and storage facility requires no more than 1 hour of inspection per day at a cost of $10 per hour.

5. The oxygenless generator can operate between 2000 SCFH and 10000 SCFH.

6. When less than 2000 SCFH are required, the machine operates at its lowest capacity of 2000 SCFH, the cost of natural gas is $.60/Therm, and the cost of electricity is $.07/KWH.

7. Buildings can be sealed or lined to reduce losses to not more than 5% of their volume per day. However, losses of 10% and 20% of the storage volume per day were also used in determing costs. Experience in controlled atmospheric storage indicates the 5% figure is a reasonable figure.

8. 25% of the total volume is purged at one time.

9. The number of cubic feet of storage required is determined by assuming 80 cubic feet of storage per ton of almonds.

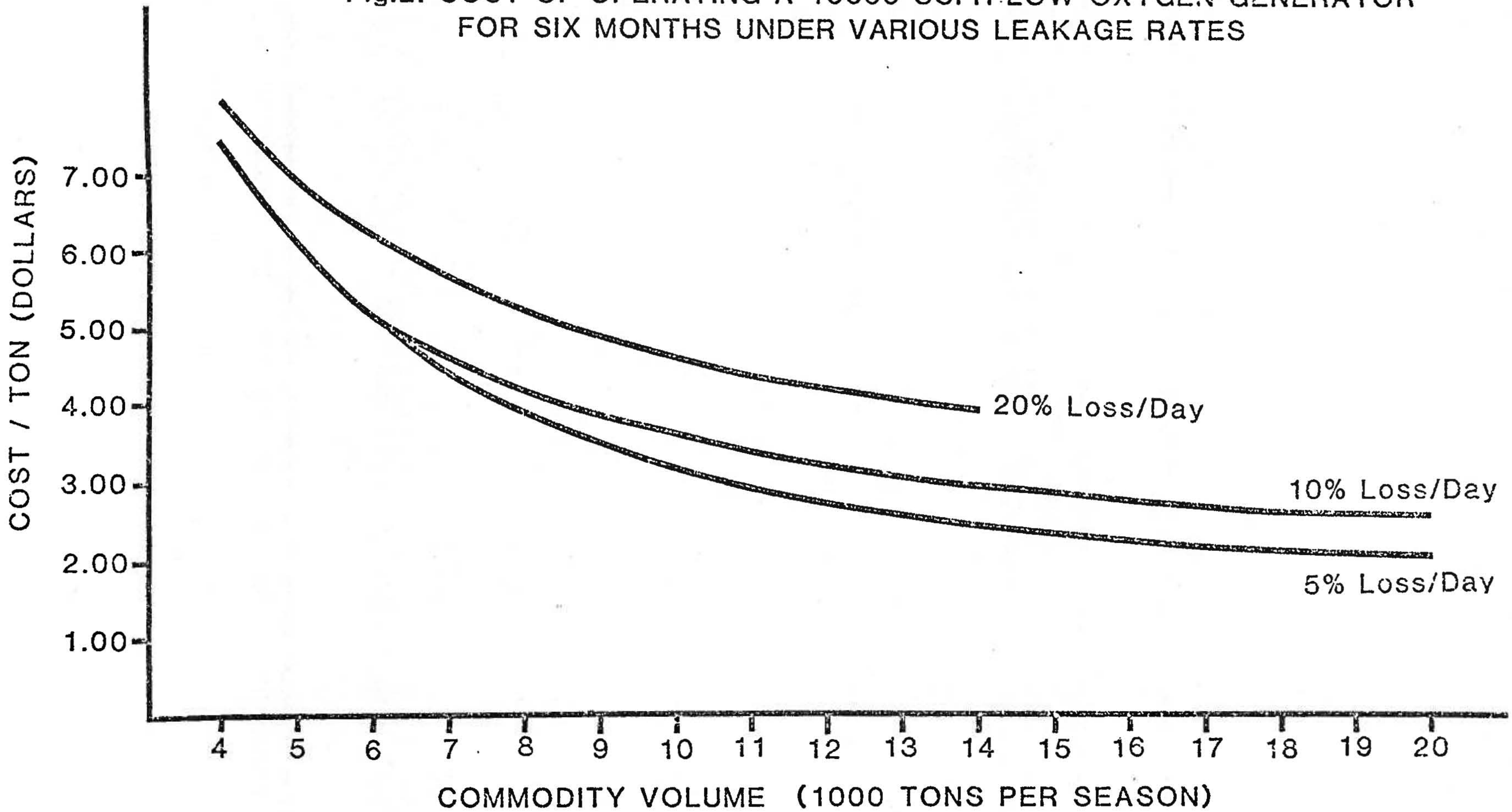
The results of this analysis indicate that with a loss of 5% of the volume per day the cost for 4,000 tons is calculated to be $7.48/ton and this cost declines to $2 per ton when 20,000 tons are stored under an oxygenless atmosphere for 180 days or six months. When the loss per day is doubled to 10% of the storage volume, the cost for the lesser tonnages (4,000-6,000 tons) is equivalent to the cost at 5% losses. This is because the required maintenance levels, although less at 5%, must be maintained at 2,000 SCFH. The 10,000 SCFH oxygenless generator can not operate below 2,000 SCFS. However, with more than 7,000 tons the differences due to the additional loss become apparent. With 20,000 tons and a 10% loss per day, the cost per ton for 6 months of oxygenless storage is calculated to be $2.51/ton. With a 20% loss of volume per day in the storage building, more than 10,000 SCFH are required for a storage facility holding 16,000 tons or more. Hence, the cost per ton is not calculated for 16,000 tons or more because the storage facility will require more than 10,000 SCFH to maintain a 20% loss per day. When losses are of this magnitude, costs can be estimated for smaller structures and are estimated to be $7.98/ton for 4,000 tons falling to $3.98/ton for 14,000 tons. This information is summarized in Figure 2 and Table 6.

No direct comparisons are made with the cost of using methyl bromide because of a lack of information. However, it should be noted that at 3.5 lbs. of methyl bromide per 1,000 cubic feet of storage space requires 5,600 lbs. of material for 20,000 tons and at $.90/lb. this equates to $5040.00. If this is done 6 times or once a month, material costs alone are $1.51/ton.

Table 6. Cost of Operating a 10,000 SCFH Low Oxygen Generator For Six Months for Various Leakage Levels for Almond Storage

	Volume of Storage Lost/Day		
Tons	5%	10%	20%
4,000	$7.48/ton	$7.48/ton	$7.98/ton
5,000	6.05	6.05	6.85
6,000	5.11	5.11	6.12
7,000	4.44	4.58	5.59
8,000	3.93	4.18	5.19
9,000	3.53	3.86	4.87
10,000	3.22	3.62	4.62
12,000	2.72	3.24	4.28
14,000	2.48	2.98	3.98
16,000	2.27	2.77	
18,000	2.12	2.62	
20,000	2.00	2.51	

Fig.2: COST OF OPERATING A 10000 SCFH LOW OXYGEN GENERATOR FOR SIX MONTHS UNDER VARIOUS LEAKAGE RATES



To this figure must be added labor and other equipment costs. It would appear that for large volumes with a 5% or even 10% loss per day oxygenless atmospheres are very cost competitive.

Table 7 summarizes the various factors in insect control for the methods of treatment. Certainly all methods of treatment are effective with respect to killing insects; however, oxygenless storage does require more time. It also does not require residue sampling as does methyl bromide. All methods provide a lethal atmosphere. It might be argued that methyl bromide and magnesium phosphide are somewhat more hazardous for those working with them than those working around the oxygenless generator. The oxygenless atmosphere substantially reduces fire danger and possible the cost of fire insurance although we were unable to obtain a cost comparison. Oxygenless storage does require considerable capital but needs considerably less labor than the other alternatives. If this cost can be spread over a sufficient volume, the labor savings appear to more than compensate for this higher capital cost. Another possible but unsubstantiated factor is the benefit to product quality of an oxygenless atmosphere. It is possible that quality retention is better maintained under this type of storage.

If such a system can fit into a processor's production schedule, the cost factor plus the other advantages of worker safety, reduced labor, fire safety, no residues, no residue sampling, make this a technology warranting further consideration by this industry.

Table 7. Summary of Insect Control Factors

	Method of Treatment			
	Methyl Bromide	Magnesium Phosphide	Oxygenless Storage	Oxygenless Storage with Heat Recovery
Efficacy	Excellent	Excellent	Excellent	Excellent
Time Required	12-24 hrs	72 hrs	4-8 days	4-8 days
Residual Testing	Yes	?	None	None
Worker Safety	Very Dangerous	Very Dangerous	Dangerous	Dangerous
Fire Danger	No effect	Concern	Reduced	Reduced
Capital Required	Small	Small	Considerable	Considerable
Labor Required	Considerable	Considerable	Small	Small
Cost:				
High Volume			Potentially Least Cost	
Low Volume	Least Cost			

Sealing Silos and Concrete Tilt-up Buildings

Up to 60% of the almond crop is exported. In the face of rising protectionism, many foreign customers of California almonds are concerned about the residues of organic and inorganic bromide. Along with local health agencies and food and agricultural agencies, foreign countries are considering lowering the acceptable levels of bromide residuals. This could mean reducing the inorganic and organic residues by up to 85%. To achieve this reduction, under the current state certification standards, it is imperative that fumigation chambers be properly sealed and their contact with methyl bromide (or other chemicals) be minimized.

For long-run planning, it may be prudent that the almond industry look to other fumigation techniques such as controlled atmosphere storage. Adopting such new fumigation techniques would not only maintain the competitive posture for the California almond industry but would also enchance it. For any of these fumigation techniques to be successful and economical, it is essential that the fumigation chamber be correctly sealed.

It appears that major portion of the California almond crop is stored and fumigated in concrete silos or concrete tilt-up (flat storage) building. To make such storage facilities tight, it is important to choose the "right" sealing materials. The selection of "wrong" kinds of materials coupled with poor workmanship or lack of experience could actually exaggerate the leakage problem rather than diminish it. While it is true that no sealing material is going to withstand large structural movements during loading, it has been suggested by Mr. Bill Woodcock (Wood-Kon Pty Ltd., Perth, Australia), that the following criteria be used in selecting a sealing product.

Some products that meet these requirement and are widely used are: Envelon® (US, Australia), Formrok®, Westolon®, Acronye®, Siloflex® (all Australian), and Gacoflex® (U.S.). In order for any of these products to perform successfully, it is very important that the surface must be properly prepared. The surface must be clean and free of loose particles, oil, grease, asphalt, and any other foreign materials. This could be achieved by washing the surface with high pressure water or detergents such as Trisodium phosphate (TSP). Of course, different sealing products have different application techniques and these are usually supplied by the manufacturer. Many of these products could be sprayed on with an airless sprayer. Special care is needed when sealing wall to wall joints or wall to ceiling joints. If the gaps are large they should be filled with polyurethane foam prior to the sealant application. Moreover, it is critical that the corners be sealed properly. In the corners, a peel is preferred to break. This could be achieved by reinforcing corners with fiberglass mesh or any other suitable reinforcing fabric. This flexible type of sealing is needed due to structural movements of the building when storage facilities are being filled. Reinforcing fabrics give the sealant film greater flexibility and lower percent elongation to accommodate the developing gap. Polycholoroprene type films are known to give best results for this purpose. Other suitable materials for use in corners are Acrylic and PVC coatings. Some costs estimates for sealing are given below:

Suggested Criteria for Selecting a Sealant

1. Must be flexible and be able to bridge and seal gaps up to 2 mm with no failure.
2. Must withstand high and low temperatures.
3. Have good adhesion to both metal and concrete surfaces.
4. Be suitable for use with food stuffs.
5. Not creep or perish.
6. Have good abrasion resistance if used internally, and be sunlight resistant if used outside.
7. Must be stable to various gases, i.e. not react or break down in the presence of any fumigants.
8. Must be easily repairable.
9. Material and application costs must be reasonable.
10. Have life of at least ten years.

Estimated Costs of Partial Sealing

A. 100'x100'x42' concrete tilt-up with 4 partitions wall to ceiling joints with 12"x12" L-shaped double-coated, wall-to-wall joints sealed with 12" wide strip double-coated.

Sealing material		$ 1326.40
Reinforcing fabric		1500.00
Labor		1728.00
	Total cost	$ 4554.40
		or 1.084 cents/ft^3

B. 24'x100' vertical concrete silo

Sealing material		$ 100.00
Reinforcing fabric		50.00
Labor		150.00
	Total cost	$ 300.00

Per cubic feet cost is insignificant

Estimated Costs of Full Sealing

A. 100'x100'x42' concrete tilt-up with 4 partitions. All surfaces double-coated.

Sealing material		$17,440.00
Reinforcing fabric		1,500.00
Labor		2,160.00
	Total cost	$21,100.00
	or	5.02 cents/ft^3

B. 24'x100' vertical concrete silo All surfaces double-coated.

Sealing material		$ 3,014.40
Reinforcing fabric		50.00
Labor		471.00
	Total cost	$ 3,535.40
	or	7.8 cents/ft^3

Estimated Costs of Sealing with Heavy Duty Inside Liner

A. 100'x100'x42' with 4 partitions.

Installed Price of liner @ $1.39/ft^2$	
Total cost	$60,604.00
or	14.43 cents/ft^3

B. 24'x100' vertical concrete silo

Total cost @ $1.39/ft^2	$10,475.04
or	23 cents/ft^3

Comparative Costs of Sealing

	100'x100'x42' Concrete tilt-up	24'x100' Concrete silo
I. Partial Sealing	1.084 cents/ft^3	Insignificant
II. Full Sealing	5.02 cents/ft^3	7.8 cents/ft^3
III. Sealing with heavy duty fabric liner	14.43 cents/ft^3	23 cents/ft^3

	Dimension	Building Cost	Loader Cost	Total Cost	Volume Useable	Tonnage at 23.51 b/ft^3	Building Cost per ft^3	Total cost per ft^3	Years Life	Cost per ft^3/yr
Silo - Small										
Diameter	20'									
Height	50'									
Wall Thickness	6"									
Data		$32,000	$16,000	$48,000	15708 ft^3	185 tons	$2.04	$3.05	30	$.10
Silo - Large										
Diameter	20'									
Height	100'									
Wall Thickness	8"									
Data		$75,000	$38,000	$113,000	31416 ft^3	370 tons	$2.39	$3.60	30	$.12
Flat storage										
Length	100'									
Width	100'									
Height	42'									
Data		$263,000	$220,000	$483,000	340425 ft^3	4000 tons	$ .77	$1.41	30	$.05
Bantam System										
Diameter	220'									
Data		$171,000	$132,000	$303,000	1000000 ft^3	11750 tons	$ .17	$ .30	10	$.03

Alternative Storage Types

We have gathered information on several different storage types. Clearly there are as many storage types as there are particular needs. Furthermore our data are from a limited number of sources. Actual figures may vary considerably. It is important to note that the cost of designing and constructing an airtight building has been quoted as approximately 5% over a non-airtight structure provided it is made airtight at the time of construction. There are construction firms that specialize in making airtight structures. We have the names of several of them in the State of Washington where controlled atmospheric storage is standard practice in the apple industry. In general, our survey indicates silos are the most expensive form of storage although they may be the easiest to adapt for oxygenless storage. The Bantam System may be the least expensive for very large volumes although it is unproven for almonds.

Qualitative Measures of Storage Types

	Silo	Flat	Bantam
Capital/ft^3	Most		Least
Years Life	Many	Many	Modest
Cost/ft^3/Year	Most		Least
Alternate Uses	Few	Many	Few

11th ANNUAL ALMOND RESEARCH CONFERENCE, DECEMBER 6, 1983, FRESNO, CALIFORNIA

Project No. 83-Q7 - Tree and Crop Research
Controlled Atmosphere

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Objectives: (1) To conduct laboratory studies on decreasing insect kill times with controlled atmospheres. (2) To complete field testing of generated low oxygen atmosphere in almonds. This is in conjunction with Dr. John Baritelle. (3) To determine effect of CO_2 on almond quality. (4) To conduct a comparative field test of carbon dioxide versus low oxygen atmosphere for insect control in stored almonds for determining cost effectiveness and time for insect mortality.

Interpretive Summary: Control of navel orangeworm requires a longer exposure time to a low-oxygen atmosphere or to a 60% carbon dioxide atmosphere than that required for control of Indianmeal moth. For complete mortality, both insects required slightly less exposure time to the low-oxygen atmosphere than to the carbon dioxide-enriched atmosphere. Temperature effects on these two insect species at three levels of oxygen or carbon dioxide are currently being determined so that more complete exposure-time schedules may be developed.

Field testing of the generated low-oxygen atmosphere has been completed, but analysis of this data has not been completed. Tests were conducted in concrete silos and in a concrete tilt-up (construction type) storage room. Although initial tests were successful in killing the navel orangeworm, the storage structures were found to have excessive leakage. Dr. John Baritelle is making a cost analysis of the low-oxygen application and comparing these costs with those for methyl bromide and phosphine fumigation. For more optimum effectiveness when low-oxygen atmospheres or fumigants are used, storages must be sealed to prevent loss of the atmospheres or fumigants.

Carbon dioxide did not adversely affect almond quality when Nonpareil or Mission almonds were stored therein for three days. This work was conducted in conjunction with Dr. Glenn Fuller at the USDA, Western Regional Research Center at Albany, CA.

A field test comparing carbon dioxide versus low-oxygen atmospheres was attempted, however due to excessive leakage of the storages, the proper atmosphere (60% carbon dioxide) could not be obtained in the storage headspace. Successful use of this technology will require that storages be sealed to prevent leakage of the atmosphere.

Experimental procedure: Low-oxygen atmospheres: Two types of almond storages used in these tests were a concrete silo of 40,000 ft^3 volume and a concrete tilt-up building of 100,000 ft^3 volume. Atmosphere for these tests was produced in a portable generator and consisted of ca. 0.5% oxygen, 13% carbon dioxide and 86% nitrogen. The generated atmosphere was introduced into the bottom of the storages and the existing internal atmosphere was allowed to exit at the top during the purge phase. After the purge was completed, the rate of introduction was reduced until the internal atmosphere remained at 0.5% oxygen. The storages were filled with inshell almonds except for one silo test where the purge phase was conducted during the almond filling operation.

A test utilizing carbon dioxide (CO_2) for treating a silo was also conducted. Here, a tanker of liquid CO_2 was utilized in conjunction with a vaporizer. The CO_2 was introduced into the headspace of the silo.

Dr. John Baritelle and Mindy Sandhu have conducted research on the economics of low-oxygen atmosphere, methyl bromide and phosphine for insect control in stored almonds. They surveyed the almond processors for their procedures and estimated the associated costs. John and Mindy also are collecting information on ways to construct tight storages and to seal existing storages.

Flavor quality of Mission and Nonpareil almonds treated with carbon dioxide for short exposures (3 and 10 day) were conducted in conjunction with Dr. Glenn Fuller, WRRC. The almonds were treated with 100% CO_2, then tasted immediately and 1 day after treatment.

A laboratory study was conducted with navel orangeworm pupae to study the effect of 60 vs 80°F temperatures, 40 vs 60% relative humidity and 0.5% oxygen vs 60% carbon dioxide in air on the time to kill this insect.

Results: At a purge rate of 8,700 cubic feet per hour, the oxygen level in the concrete silo containing inshell almonds was quickly reduced to 0.5% oxygen (Figure 1). The maintenance phase required 2000 cubic feet per minute to maintain this desired oxygen level. This high maintenance level indicates that further sealing would be required to make this treatment more economical. Navel orangeworm pupae placed in the headspace of the silo were completely killed in 3.5 days, which coincides with data obtained in the laboratory. The purge test during the filling operation was considered to be successful. The oxygen level in the overhead space was reduced to 5 percent which is considered an acceptable level while the nuts are entering the silo. This method will result in reducing the time required for treatment and should result in reduced insect feeding on the almonds by the navel orangeworm.

The test with the concrete tilt-up building showed a purge to 5 percent oxygen at all sample sites. However, a leak in one corner of the building prevented a further reduction. An earthquake that had occurred between the initial seal test of the building, and the low-oxygen application, apparently damaged the building and prevented further oxygen reduction. With the size of the leak, a purge to 5% oxygen in 24 hours was considered to be excellent.

Carbon dioxide application to the concrete silo filled with inshell almonds resulted in a 60% level at all sample sites within the nuts. The headspace did not reach a killing atmosphere due to excessive leakage in the silo.

Economics of currently used fumigants, methyl bromide and phosphine and generated low-oxygen atmosphere have been estimated to be:

Estimated Costs Almond Silos

Actual Tonnage	Methyl Bromide	Magnesium Phosphide	Oxygenless	Oxygenless Heat Recovery
50,000	$2.83	$1.79	$1.51	$1.13
60,000	2.36	1.49	1.26	.95
70,000	2.02	1.28	1.08	.81
80,000	1.77	1.11	.94	.71
90,000	1.57	.99	.83	.63

Note: These are only preliminary estimates and further refinements are necessary.

Several storage construction companies were contacted and information on sealing methods and materials have been obtained. New construction with tight seals require only an estimated 5 percent more in costs than regular storage. Also, sealing current storages is possible, but may be more costly.

Carbon dioxide did not adversely affect the flavor of Mission and Nonpareil almonds, thus indicating that short-term storage of almonds in CO_2 is acceptable.

Laboratory tests with navel orangeworm pupae indicate that cooler temperatures, higher humidities and higher oxygen content in storages, require longer exposures for insect kill (Table 1).

Discussion: Modified atmospheres have been shown to be an acceptable method for insect control in stored almonds. The quality of the almonds are not affected by the treatment and low-oxygen atmospheres appear to be economically feasible in comparison with methyl bromide and phosphine. Further research should be to study ways of reducing insect kill times by combination treatments with CO_2, O_2 and N_2 and also combinations with phosphine or methyl bromide or other new fumigants that may become available.

Sealing of storages is of paramount importance to make modified atmospheres and current fumigants more acceptable and economical. New methods of sealing storage are becoming available and should be explored by this industry.

Carbon dioxide treatment of almonds for long periods needs to be studied for its effect on almond quality. Also, carbon dioxide should be compared with low-oxygen atmospheres for their relative economics.

In summary, the industry has an alternative treatment of low-oxygen atmosphere available for future use. Sealing of storages will result in even better economics than has been currently shown and if shorter treatment times can be achieved, this method of insect control will be even more viable.

Publications:

Brandl, D. G., E. L. Soderstrom and F. E. Schreiber. 1983. Effects of low-oxygen atmospheres containing different concentrations of carbon dioxide on mortality of the navel orangeworm, Amyelois transitella Walker (Lepidoptera: Pyralidae) J. Econ. Entomol. 76: 828-830.

Table 1.

Time to kill navel orangeworm with low-O_2 or CO_2 atmospheres at two temperatures.

Temperature (°F)	% RH	low-O_2 (0.5%)	60% CO_2 in air
		Time(hours)	
80	40	50	54
80	60	62	65
60	40	162	176
60	60	195	208

Figure 1.

Headspace oxygen concentration, 40,000 ft silo.