OBSERVATIONS OF CO_2 SCRUBBERS FOR COMMERCIAL APPLE

CA ROOMS IN NEW YORK STATE

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In this paper we will briefly discuss the number and size of CA storages in New York, the types of CO_2 scrubbers in use, and the estimated cost of scrubbing with each of the CO_2 scrubbing systems. The estimated costs are based on the following general assumptions, which apply to all of the systems we will describe: 260 tons (13,000 bushels) capacity CA rooms; operating temperature, -1° to 0°C; 6 months operation for 16 years; electricity cost, 4.25¢ per kwh; cost of lime, $75/ton; 5 kg lime/ton of fruit (.25 lbs/bushel) can be placed into the CA room without displacing apples -- additional lime displaces apples.

New York CA Storages

Recent data for CA storages in New York (Table 1) show the average CA room size is approximately 260 tons (13,000 bushels). Fifty percent of the CA

Table 1. Number and size of CA establishments in New York State

Season	No. of rooms	Total capacity Tons ($x10^2$)	Total capacity Bu. ($x10^3$)	Avg. room capacity Tons	Avg. room capacity Bu. (x1000)
1974-75	301	77.3	3.9	256	12.8
1975-76	323	84.3	4.2	262	13.1
1976-77	265	67.8	3.4	256	12.8

establishments have 1 or 2 CA rooms, 80% of the establishments have 4 or less CA rooms (Table 2). In contrast with many other apple growing regions, most of the CA storages in New York are owned and operated by individual fruit growers. Thus, most of our CA operators are fruit growers with a few, small CA rooms.

Table 2. CA storage rooms at New York establishments. 1976-77.

No. of CA rooms at each establishment	CA establishments No.	CA establishments %
1	25	30
2	16	20
3	11	14
4	13	16
5	4	5
6 or more	12	15

CO_2 Scrubbers in Use

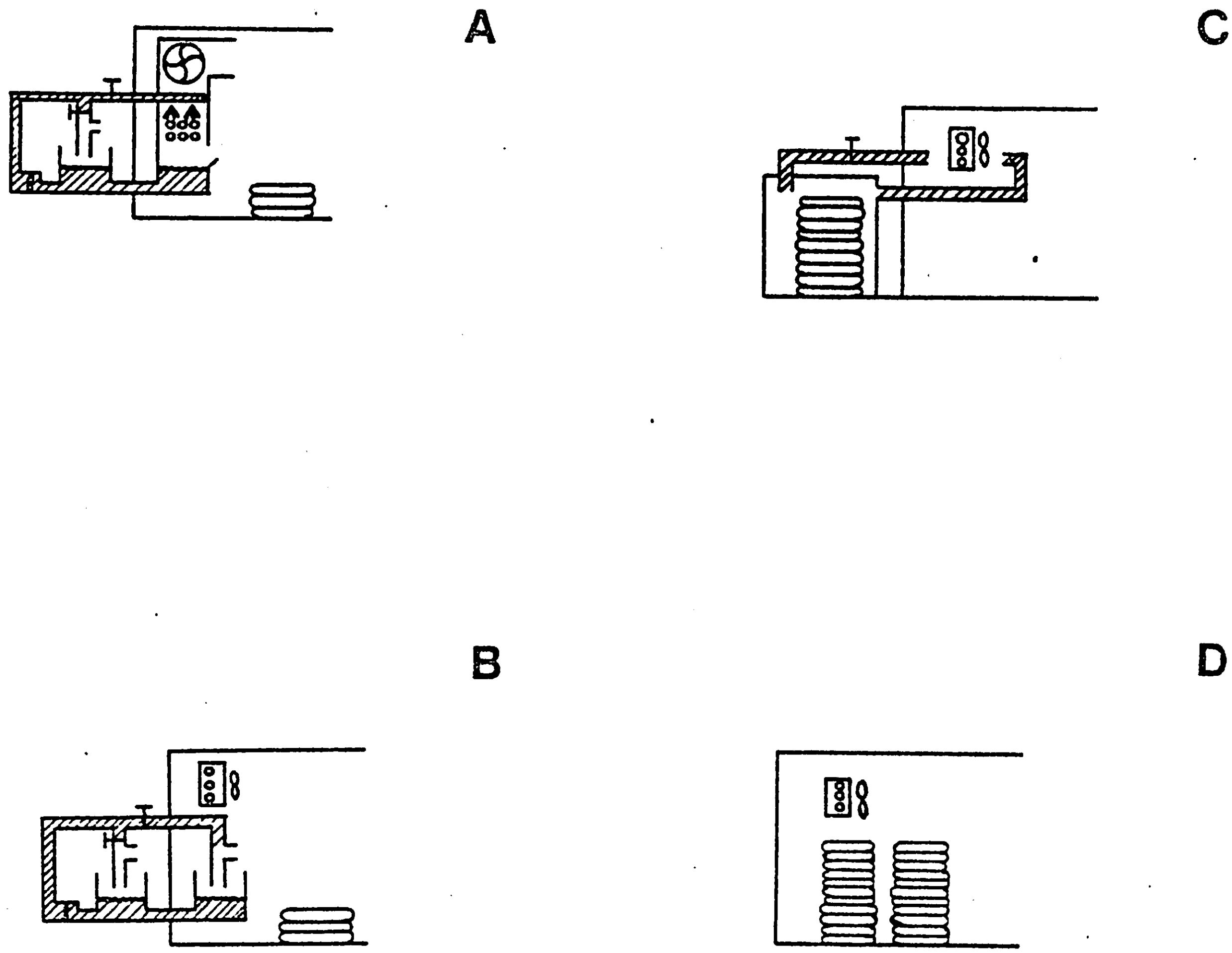
Excess CO_2 is removed from these CA rooms by circulating water, by lime, by a combination of circulating water and lime, or by activated carbon scrubbers. So far as we know, there are no longer any molecular sieve scrubbers in use in New York.

The most common CO_2 scrubber is shown in simple schematic form in Fig. 1A. Brine-water is pumped over the evaporator coil where it absorbs CO_2. The brine-water is gravity fed to a reservoir outside the CA room. Brine-water is pumped from this reservoir through an aerator (where the CO_2 diffuses into the air) and also into the CA room. A small quantity of lime (2-5 kg/ton, 0.1-0.25 lbs/bushel) is placed directly inside the CA room to absorb the extra CO_2 evolved during the O_2 pulldown and early CA period. Most of our wet-coil CA rooms are CO_2 scrubbed with this or with a slight modification of this type of equipment. The negative cash flow (Table 3) for this system is based on the following additional assumptions: cost of aerator and plumbing, $1200; cost of installation, $100; life expectancy of electric motor, 3 years; life expectancy of brine pump bearing assemblies, 2 years; electrical cost, $367/year; cost of lime for pulldown (5.7 kg/ton, 0.25 lbs/bushel), $122/year; 12 blocks of salt, $12/year.

Table 3. Negative cash flow ($) for the first 6 seasons of operation with a brine-water CO_2 scrubbing system.

Item	Season of operation* 0	1	2	3	4	5	6
Cost + installation	1300	---	---	---	---	---	---
Elect. + lime + salt	----	501	501	501	501	501	501
Elect. motor	----	---	---	65	---	---	65
Bearing assembly	----	---	130	---	130	---	130
Cash flow	1300	501	631	566	631	501	696

* Subsequent seasons follow same pattern.



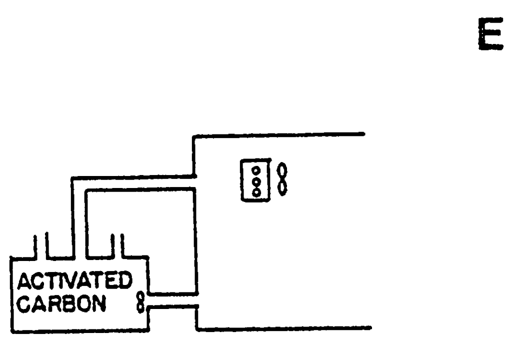


Fig. 1. Simple schematic diagrams of CO_2 scrubbers in use in New York: A - brine water scrubber; B - separate water scrubber; C - lime box scrubber; D - lime in CA room, E - activated carbon scrubber.

The other scrubbing methods we will discuss are used for dry-coil CA rooms.

A relatively new innovation is the water scrubber shown schematically in Fig. 1B. It is simply two of the aerators shown in Fig. 1A: one aerator inside and one outside the CA room. No salt brine is required with this system. As with the other water scrubber, a small amount of lime is placed directly into the CA room to handle the extra CO_2 generated during the O_2 pulldown and the early part of the CA season. Three advantages of water scrubbing are: addition of water vapor to the CA atmosphere; ammonia leaks in the CA room are quickly detected because the ammonia is given off by the aerator outside the CA room; odors, such as burnt electrical insulation, are rapidly removed from the CA room. The negative cash flow (Table 4) for this system was based on the following additional assumptions: the electric motor lasts 5 years and the bearing assembly lasts indefinitely because there is no need for salt with this system.

Table 4. Negative cash flow ($) for the first 5 seasons of operation with a separate water scrubbing system for CO_2 removal.

Item	Season of operation*					
	0	1	2	3	4	5
Cost + installation	1500	---	---	---	---	---
Elect. + lime	----	489	489	489	489	489
Electric motor	----	---	---	---	---	65
Cash flow	1500	489	489	489	489	554

* Subsequent seasons follow same pattern.

The second most common CO_2 scrubber in New York is the lime box, which is located adjacent to the CA room (Fig. 1C). The box is usually sized to hold 11.3 kg lime/ton of fruit (0.5 lbs/bushel). When the lime is spent, it is replaced with a charge of fresh lime. Atmosphere from the CA room is circulated through the lime box by the differential pressure of the evaporator fan. The CO_2 level in the CA room is controlled by a valve located in one of the pipes connecting the lime box to the CA room. The negative cash flow (Table 5) for this system was based on the following additional assumptions: 23 kg lime/ton (1 lb/bushel) is required each season; lime box (3.5 cu ft/bag of lime) holds half the required charge and cost $400 to build.

Table 5. Negative cash flow ($) for the first 4 seasons of operation with a lime box CO_2 scrubbing system.

Item	Season of operation*				
	0	1	2	3	4
Cost of box	400	---	---	---	---
Lime	---	488	488	488	488
Cash flow	400	488	488	488	488

* Subsequent seasons follow the same pattern.

A few operators place all the lime directly into the CA room (Fig. 1D). A charge of 17 kg/ton (0.75 lbs/bu) will usually keep the CO_2 below 3% until February. If the room is scheduled for late opening, additional bags of lime are placed into the CA room where the CO_2 reaches 3.5%. The negative cash flow (Table 6) for this system was based on the following additional assumptions: 23 kg lime/ton (1 lb/bushel) is required each season; 75% of this lime will displace apples; each 16 bags of lime displaces apples occupying the space of 0.4 ton (20 bushel) bulk box of apples; the opportunity cost lost by displacing apples with lime is $18/bulk box.

Table 6. Negative cash flow ($) for the first 4 seasons of operation with lime placed directly into the CA room to remove all excess CO_2 during the entire CA storage season.

Item	Season of operation*				
	0	1	2	3	4
Lime	---	488	488	488	488
Displaced apples	---	216	216	216	216
Cash flow	---	704	704	704	704

* Subsequent seasons follow same pattern.

Finally, there are several activated carbon scrubbers in use (Fig. 1E). Most of these units were manufactured by the Tectrol Corporation. There is 1 Sulzer and 1 Carbosorb activated carbon scrubber in New York and Massachusetts, respectively. The negative cash flow (Table 7) for the Sulzer ADSO-20 activated carbon scrubber was based on the following additional assumptions: cost of scrubber, $4700 delivered; installation, $150; electric cost, $68 each season (220 volts, 1.6 amps); charcoal bed replaced after each 5 seasons of operation.

Table 7. Negative cash flow ($) for the first 5 seasons of operation with a Sulzer ADSO-20 activated carbon CO_2 scrubber.

Item	Season of operation*					
	0	1	2	3	4	5
Cost + installation	4850	---	---	---	---	---
Electricity	----	68	68	68	68	68
Charcoal	----	---	---	---	---	150
Cash flow	4850	68	68	68	68	218

* Subsequent seasons follow same pattern.

The negative cash flow for the Carbosorb-25 activated carbon scrubber (Table 8) was based on the following additional assumptions: cost of scrubber, $4500 delivered; cost of installation, $150; electric cost, $92 each season, operating 12 hours per day; charcoal replacement after 5 seasons of operation, $150. Since the Carbosorb-25 is reputed to have the capacity to scrub CO_2

for 500 tons (25,000 bushels) an additional 260 ton (13,000 bushel) capacity CA room could be scrubbed for the cost of the electricity to run the scrubber for 24 instead of 12 hours a day.

Table 8. Negative cash flow ($) for the first 5 seasons of operation with a Carbosorb-25 activated carbon CO_2 scrubber.

Item	Season of operation*					
	0	1	2	3	4	5
	(one 260 ton CA room)					
Cost + installation	4650	---	---	---	---	---
Electricity	----	92	92	92	92	92
Charcoal	----	---	---	---	---	150
Cash flow	4650	92	92	92	92	242
	(for each of two 260 ton CA rooms)					
Cost + installation	2325	---	---	---	---	---
Electricity	----	92	92	92	92	92
Charcoal	----	---	---	---	---	150
Cash flow	2325	92	92	92	92	242

* Subsequent seasons follow same pattern.

Net Present Value Comparison of CO_2 Scrubbers

We used the net present value to compare the costs for the CO_2 scrubbing systems outlined above. These values assume: costs of construction were paid at the beginning of the year; the operating costs were paid at the end of each year; the cost of capital is 7% or 12%; 16 year time period; no salvage value of equipment; no inflation.

The net present value comparison is presented in Table 9. The following general observations can be made from these data.

1. The separate water scrubber is cheaper than the brine-water scrubber primarily because the costs for salt and bearing assemblies are eliminated. The costs for brine corrosion inhibitor were not included because most operators do not use recommended brine corrosion inhibitor.

2. The cost of constructing a lime box is more than offset by the loss in storage revenue when lime is placed directly into the CA room.

3. Storage operators with dry-coil CA rooms should give serious consideration to purchasing an activated carbon CO_2 scrubber if the machine can be used near its rated capacity. Although the initial cost of these units is high, the annual and long term costs are low.

Table 9. Net present value comparison ($) of various CO_2 scrubbers. (See text for assumptions.)

Scrubber	With no tax consideration cost of capital 7%	With no tax consideration cost of capital 12%	With owner in 30% tax bracket[4]
Brine-water	-6,776	-5,332	-5,261
Separate water	-6,221	-4,980	-4,779
Lime in CA room	-6,650	-4,910	-5,343
Lime in box	-5,010	-3,803	-3,982
Sulzer ADSO-20	-5,730	-5,485	-3,960
Carbosorb-25[1]	-5,757	-5,452	-4,003
Carbosorb-25[2]	-3,432	-3,127	-2,449
Carbosorb-25[2,3]	-4,376	-3,825	-3,208

1 - 500 ton (25,000 bushel) capacity machine on one 260 ton CA room.
2 - same unit for each of two 260 ton CA rooms.
3 - assumes $100/year for repairs.
4 - assumes 10% investment tax credit, 10 year straight line depreciation and a cost of capital of 7% before tax.