LARGE-SCALE TRIALS ON THE USE OF CONTROLLED ATMOSPHERES FOR THE CONTROL OF STORED GRAIN INSECTS

S. NAVARRO, M. GONEN, and A. SCHWARTZ
Stored Products Division, Agricultural Research Organization, P.O. Box 6, Bet Dagan, ISRAEL

INTRODUCTION: Research on the technology of the application of controlled atmospheres as a substitute for the use of chemical insecticides, has received special attention in view of the problems arising from the development of insecticide resistance and pesticide residues (1). The controlled atmosphere storage of dry grain (for cereals below 13% moisture content) consists of altering the atmospheric composition within a structure containing the grain to give a combination of the atmospheric gases lethal to insects.

Various combinations of atmospheric gases have been suggested for the control of stored-product insects. Controlled atmospheres which could be utilized for grain storage are those with reduced oxygen (O_2) tension and/or those with an increased carbon dioxide (CO_2) content. Means of producing controlled atmospheres include the purging of airtight silos with nitrogen (N_2) (to reduce the O_2 to less than 2%) or CO_2 from tankers (to produce a mixture of 60% CO_2 in air), or to use low O_2 atmospheres produced by hydrocarbon burners (typically producing atmospheres containing 13% CO_2, less than 1% O_2, with the balance N_2). (2, 3).

Field trials aimed at using N_2 or CO_2 to establish and maintain an atmosphere containing 1.5% O_2 or 60% CO_2 have been carried out (1, 4). In these trials the approach was to seal silos to a standard which minimized the amount of gas required to maintain the atmosphere within acceptable limits. Although the use of N_2 or CO_2 from gas tankers gave satisfactory results, they may require long hauls to the site of use. It was demonstrated that on-site generation using exothermic inert-atmosphere generators was promising also (5).

Generation of an inert atmosphere may be possible employing propane burners using a flame generator or by catalytic combustion. The large-scale trials described in this paper were aimed at ascertaining the feasibility of using a catalytic O_2 converter to generate atmospheres for the control of stored grain insects.

MATERIALS AND METHODS: Inert atmosphere generator. The generator consisted of an O_2 converter type CIE manufactured by Sulzer, Switzerland, used in the fruit conservation industry. During operation, propane gas is combusted catalytically without flame, and the exhaust gases are blown into the storage structure by a blower at a rate of 144 m^3/hr. Combustion takes place in the reaction chamber and following it the gases are cooled by water in a spray cooler. Water removed from the gases leaves the cooler through a seal leg. The exhaust gases were conveyed to the silo by a P.V.C. pipe of 105 mm i.d. The O_2 converter was operated in recirculation, with the gases blown through the roof of the silo and sucked into the converter through a pipe connected to the aeration duct.

Operation of the O_2 converter. The converter was operated in two phases, the purge and the maintenance. In the purge phase the converter was operated continuously until the desired atmosphere was obtained within the bin. Towards the end of this phase, when the O_2 concentration within the bin dropped to 3% to maintain the converter in operation, a calculated flow of ambient air was permitted to penetrate through the recirculated gas entry duct of the converter. In this way O_2 concentrations lower than 0.5% were created within the bin.

In the maintenance phase, the atmosphere created within the bin was maintained for the required period of time. To achieve this it was necessary to operate the converter intermittently to maintain the desired gas concentration against leakage.

Experimental bins. Experiments were conducted in three welded steel bins containing 1252, 1193, and 1106 tons of wheat (referred to in the text as bins A, B, and C, respectively). Bins A and B were similar in shape and dimensions: 14 m diameter, 11 m high, with a flat floor (Figure 1). Bin C had a 9.8 m diameter and was 23.5 m high, with a conical base.

RESULTS AND DISCUSSION: Operation of the O_2 converter. Data obtained on operating the converter in five trials are shown in Table I. The estimated operation time required in the purge phase for reducing the O_2 concentration from 21 to 0.5% was 57, 59, and 54 hr for bins A, B, and C, respectively. However, from Table I it is seen that in different trials the reduction of O_2 concentration was achieved in 37.3 to 74.4 hr and only in trial no. IV did the operation last 60.3 hr, as expected. The main factors responsible for these differences were the gastightness level of the bin and the existing insect population. In trials no. I and III, a longer operation time was required due to low gastightness and in trial no. II the initial high insect population contributed to consumption of O_2 by respiration, thus shortening the converter operation period.

The catalytic converter consumes electricity for the heat exchanger before it reaches its operation temperature, and for the blower. From Table I it is seen that the mean energy consumption was 3.01 kw/hr. However, in trials no. II to IV the energy consumption was higher, apparently due to a failure in the

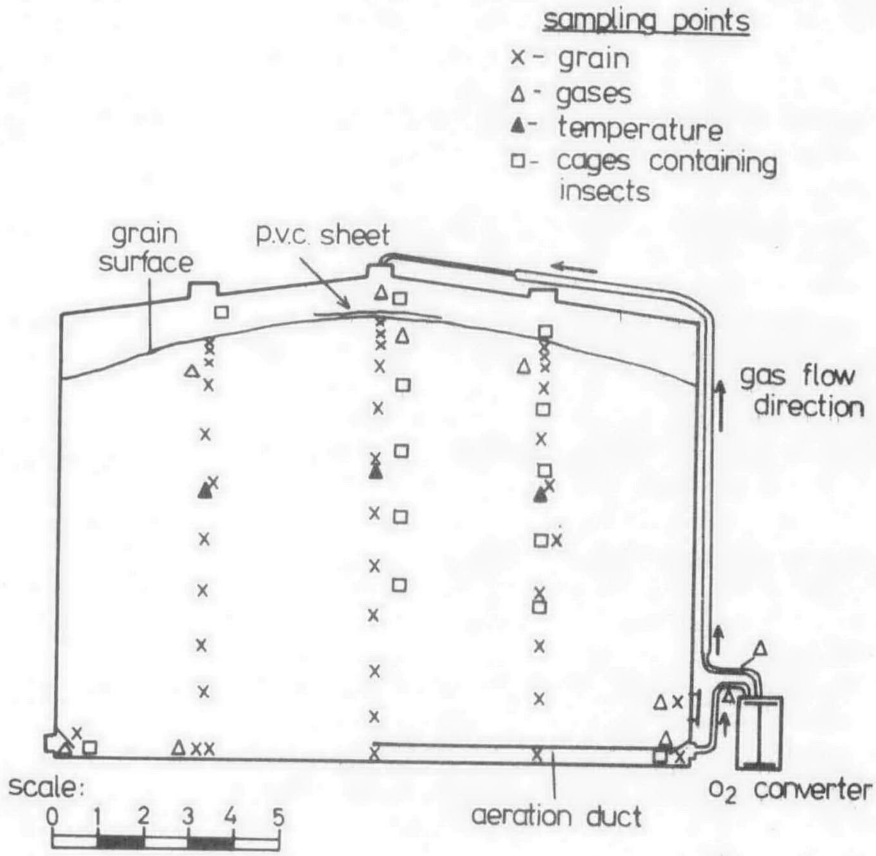

FIGURE 1. Vertical section of the steel bin containing 1193 tons of wheat on which the oxygen converter was tested.

reaction chamber. The results obtained in trials no. I and V were closer to the manufacturers' specifications. The energy consumption during the maintenance phase was higher, due to intermittent operation requiring repeated preheating at each operation stage.

The heated gases were cooled using tap water at a mean rate of 1300 l/hr (Table I). This may present a problem in dry areas, where the water supply is limited. However, an alternative that should be considered for cooling the gases is the use of recirculated water through cooling towers.

Mean propane gas consumption was 1.17 kg/hr (Table I). The longest operation period in trial no. V was 114.5 hr (including the maintenance phase) for which the propane consumption was 136 kg. This figure should be compared with that in the method of application of N_2 which requires approximately 1315 kg of N_2

Table I. Data obtained during the operation of the oxygen converter on three different experimental bins containing wheat

Bin capacity (tons of wheat)	Trial No.	Phase of operation a = purge b = maintenance	Date of trial	Operati time (hr)	Energy consumption rate (kw/hr)	Water required for cooling gases (l/hr)	Propane gas combusti (kg/hr)	Rate of water condensing in the exhaust pipe (l/hr)	Rate of O_2 consumption m^3/h
1252	I	a	March-April 1975	71.7	1.42	1017	1.28	0.90	2.7
1193	II	a	July 1975	37.3	2.80	1371	1.16	1.03	-
	III	a	Sept. 1975	74.4	4.24	1086	1.08	1.26	-
	IV	a	Jan. 1976	60.3	4.21	1852	1.12	1.53	2.6
		b	Jan. 1976	19.5	7.21	1308	1.21	1.07	-
1106	V	a	July 1977	74.2	1.49	-	1.08	0.84	-
		b	July-Augu 1977	40.3	2.72	-	1.38	1.63	-
				Mean	3.01	1300	1.17	1.16	2.65

(calculated for maintaining 1% O_2 for three weeks), based on suggested practical requirements (2). Under conditions in which transport of nitrogen constitutes one of the major costs and necessitates long hauls to the site of use, the method of on-site generation of the controlled atmosphere should be considered.

The exhaust pipe of the converter was connected to the apex of the bin (Figure 1). This was done to permit the water vapor in the gas mixture, which had 90-96% relative humidity, to condense in the pipe. The mean rate of this condensed water collected from the bottom of the pipe was 1.16 l/hr (Table 1). The water was collected to prevent its entry into the bin, thereby increasing the moisture content of the grain.

The calculated mean rate of O_2 consumption by the converter was 2.65 m^3/hr, very close to the figure of 2.6 m^3 by the manufacturers of the converter.

Changes in gas concentration. Typical changes in concentration of O_2 and CO_2 within the bin obtained in trial no. IV are shown in Figure 2. In this trial the purge phase lasted

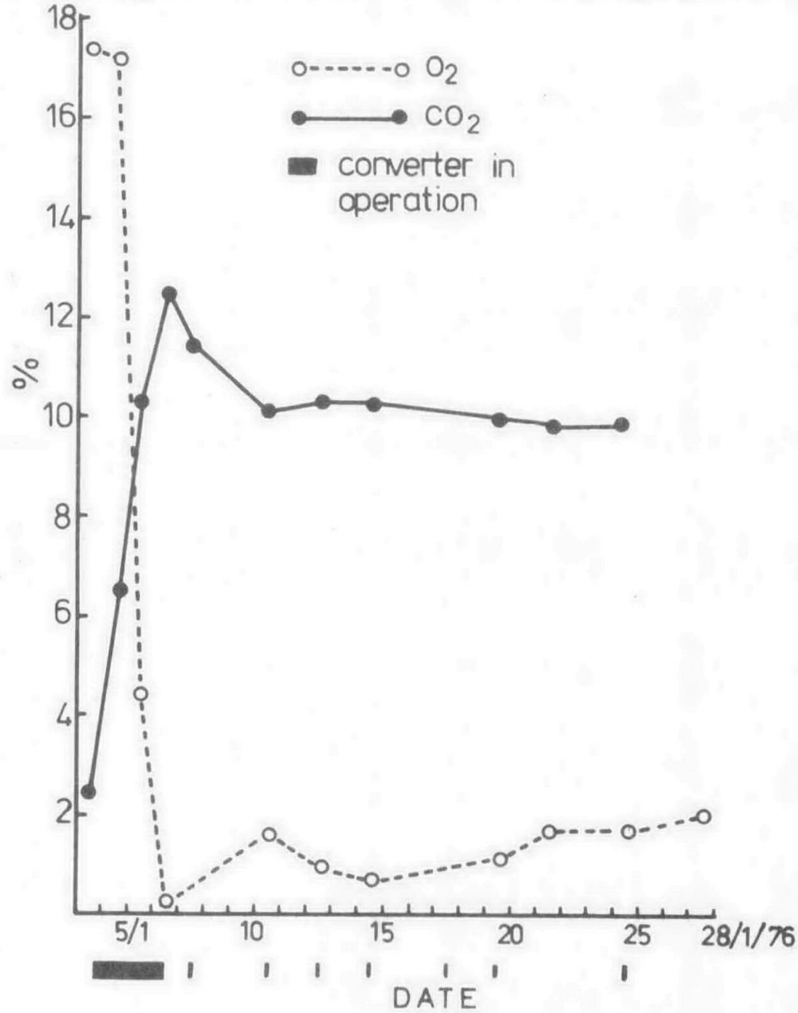

Figure 2. Changes in gas composition by intermittent operation of oxygen converter for a total of 79.8 hr in a horizontal steel bin containing 1193 tons of wheat

60.3 hr, during which the average O_2 concentration was reduced to 0.2%. During the maintenance phase, which lasted 21 days, the O_2 concentration was maintained below 2% by intermittent operation of the converter for a total of 19.5 hr.

Results of other trials showed that at the end of the purge phase O_2 concentration was reduced to the range of 0.2-1.2%. Operation of the converter in all the trials resulted in an increase in CO_2 level to 9.8-13.3%.

In tests carried out using two exothermic inert-atmosphere generators producing 850 m^3/hr of inert atmosphere, concentrations of 0.1-0.9% O_2 were obtained after 24 hr in a bin of 540 tons of wheat (5). Although the volume of the atmosphere and the rate of O_2 reduction by these large units were high, the results of the present study support the feasibility of inert-atmospheric generators for producing low O_2 atmosphere in structures containing grain.

Moisture content and grain temperature. The moisture content of wheat samples taken from different layers of the bin showed that the surface layer was the most markedly affected by purging the grain (Table II). Grain samples taken from 0-10 cm

Table II. Moisture content of grain before and after controlled atmosphere purging, and temperature of the bulk in experimental bins containing wheat

Trial No.	Moisture content of grain (%)				Temperature of grain(°C)
	Surface layer*		Within the bulk		
	Before purging	After purging	Before purging	After purging	
I	12.2	12.8	11.6	11.8	20
II	12.5	13.0	10.7	10.4	36
III	12.2	12.8	10.2	10.1	28
IV	13.0	13.6	10.2	10.5	28
V	9.6	-	11.0	-	33

*Measured on samples taken from the top 0-10 cm of the grain bulk.

below the surface of the bulk showed an almost constant increase of 0.6% in moisture content. To enable the gases containing high humidity to disperse, a P.V.C. sheet (3 x 3 m) was placed above the bulk's surface and below the point of gas entry to the bin. This prevented moistening of grain at the gas inlet location.

Most of the grain in the bulk was not markedly affected by the humidity of the gases.

The temperature factor is an important one in determining the exposure time required to achieve insect mortality (6, 7). Temperature measurements (shown in Table II) indicate that in trial II, the highest temperature (38° C)prevailed for producing mortality at a shorter exposure time.

Insect mortality. Results of tests carried out on mortality of insects naturally found in grain and of test insects introduced into the bulk, are shown in Table III. The 100% mortality achieved in trial no. II can be attributed to the high temperature prevailing in the bulk during the trial. In contrast to this, in trials no. III and IV insects survived, especially in the surface layer and on the bin floor.

Controlled atmosphere storage has no residual effect on grain, which after treatment is subject to further damage by surviving or invading insects. Insect aggregation in an O_2 concentration that permits survival is a limitation of controlled atmosphere storage. The dispersal response of three stored product insects to atmospheric gas gradients has been investigated (8). The results obtained for *Oryzaephilus surinamensis*, *Sitophilus oryzae*, and *Rhyzopertha dominica* in the presence of a stable O_2 gradient indicated that dispersion was significantly restricted by 0.9% O_2. It appears that there is little chance of insects dispersing from low O_2 levels towards regions in the bulk having high O_2 levels as occur in the region of leaks in the structure. Insects already found in such a region may survive the treatment, and form a source for reinfesting the bulk after treatment. The surviving insect populations found in the surface layer and on the bin floor seem, therefore, to have derived from insects already existing in these locations.

The natural insect population recorded in trials no. II, III, and IV comprised, in decreasing intensity, the following species: *O. surinamensis*, *Tribolium castaneum*, *R. dominica*, and *S. oryzae*. It has been demonstrated that in 2.5% O_2, mortality of *T. castaneum* larvae and adults was 100% after 14 days' exposure at 26.7°C (9). In an atmosphere of less than 1% O_2 at 27°C, 95% mortality of *O. surinamensis* and *R. dominica* adults was obtained after exposure for 11.2 and 31.0 hr, respectively. These data suggest that the given gas concentrations for the exposure of 24 days in trial no. IV should cause complete control of insects. Survival of the natural insect population recorded in trial no. IV was found in one out of 56 grain samples taken from the bin. This sample was taken from the region around the aeration duct on the bin floor. In that location, consistently higher O_2 concentrations were recorded than at the remaining sampling points in the bin. This apparently was the cause of insect survival.

Although the mortality of test insects introduced into the bin was high, the causes of survival may be explained as

Table III. Insect mortality obtained in the natural insect population found in grain samples (1 kg), and in test insects introduced into the bin treated with controlled atmospheres

Trial No.	Exposure time (day) after start purging	Sampling location*	For natural insect population: Number of samples examined	For natural insect population: Number of insects per sample	Insect mortality (%): Natural insect population	Test insects introduced into the bin: O. surinamensis larvae	O. surinamensis adults	T. castaneum larvae	T. castaneum adults	S. oryzae larvae	S. oryzae adults	R. dominica adults
II	22	a	5	307	100	–	100	–	100	–	100	–
		b	15	65	100	–	100	–	100	–	100	–
		c	2	8	100	–	100	–	100	–	100	–
III	62	a	5	297	99.9	–	100	–	100	–	100	–
		b	44	29	100	–	–	–	–	–	100	–
		c	6	85	81.1	–	88	–	75	–	100	–
IV	24	a	5	162	100	85	100	96	100	100	100	100
		b	44	46	100	–	–	–	100	–	–	–
		c	7	81	98.1	100	100	92	96	100	100	99

* a = surface layer and head space, b = 0.3 to 9 m depth from surface of bulk, c = bin floor.

follows: (a) Insect cages containing insects were located close to bin opening in the head space and bin floor (Figure 1). Although the O_2 concentration was even during the intermittent operation of the converter, the rate of increase in O_2 levels between each operation was higher in these locations, relative to other sampling points. (b) Trial IV was carried out during the cool season (January) of the year, when ambient temperatures were in the range of 7-17°C. Temperatures at the bin periphery were significantly lower than in the grain bulk, a fact which may have contributed to test insect survival.

Gastightness of the structures. In controlled atmosphere treatment a high standard of gastightness is essential to prevent rapid gas loss. To determine the degree of gastightness, the static pressure test was applied in the present study. This test has the advantage of being independent of bin volume. The test consisted of raising the pressure within the structure by introducing different flow input rates and recording their equivalent differential pressures relative to ambient (10).

Results on static pressure - flow tests and the calculated air ingress rate calculated for different trials are given in Table IV. From the table it is seen that to maintain a static pressure of 10 Pa - the higher the flow rate required, the higher was the calculated air ingress rate that brought about an increase in O_2 level after the controlled atmosphere was generated. However, more field tests are required to collate additional information for interpreting the gastightness measurements in the light of recent developments. The results in Table IV may serve as guidelines for a comparative analysis of the gastightness in large-scale trials.

CONCLUSIONS: The results of this work indicate the feasibility of using an O_2 converter for generating controlled atmospheres in welded steel bins. The experimental structures, with slight modifications, gave a reasonable level of gastightness. However, more research is required to ascertain the feasibility of the controlled atmosphere method in bins different in size, structure, and degree of gastightness.

The application of a controlled atmosphere gave more satisfactory results in grain at high temperatures. Application of the method for insect control when the grain temperature is high, and the use of aeration subsequently to reduce grain temperature, should be considered as complementary conservation methods.

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Table IV. Results on static pressure-flow tests compared with calculated air ingress rate after controlled atmosphere was generated in welded steel bins

Bin capacity (tons of wheat)	Trial No.	Head space - to-volume ratio	n*	10^3 x b*	10^3 x Flowrate (m^3 sec^{-1}) of 10 Pa	Calculated air ingress rate (%/day)
1252	I	0.049	0.1668	3.491	5.13	2.778
1193	III	0.094	0.6930	0.418	2.06	1.373
	IV+	0.094	0.7277	0.153	0.82	0.876
1106	V	0.079	1.0319	0.130	1.40	1.024

* From equation $Q = b\Delta p^n$

p = pressure difference (Pa)

Q = input flow (m^3 sec^{-1})

+ Test carried out on same bin after gastightness was improved.

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