

Simulated Commercial Export of Mangoes Using Controlled Atmosphere Container Technology

B.C. Peacock *

LABORATORY studies, conducted both in Queensland and Thailand, have demonstrated that controlled atmosphere (CA) storage of mangoes achieves a longer storage life than cool storage alone. Optimum conditions have been shown to be 5% oxygen at 13°C. The optimum carbon dioxide level has not yet been established but trials to determine this are in progress. Initial CA studies have suggested carbon dioxide in the storage atmosphere may be detrimental to product outturn quality.

Queensland studies have been financed under a grant from the Australian Centre for International Agricultural Research as part of a collaborative project (Mango Project No. 8356) with Southeast Asian institutions. This project is due to conclude with the 1986-87 research program. In an attempt to implement results into commercial practice, it was proposed to industry that they undertake three export trials during the season with assistance from officers of the Queensland Department of Primary Industries (QDPI). Initially three export trials were proposed, each of one CA container load, to Hong Kong, Singapore and Canada. This was reduced to two proposed shipments, to Hong Kong and Singapore, when it was found that Canada had not yet legislated for minimal residue levels of certain fungicides for mangoes.

The 1986-87 season in Queensland produced an abnormally low crop due to poor flowering, and local prices for this commodity remained extremely high. Local industry representatives finally decided not to go ahead with actual export trials, but to simulate an export trial by conducting a static CA

container storage trial for 3 weeks. This paper reports the results of that trial.

Materials and Methods

Fruit for the trial were obtained from three growers' properties from the coastal Ayr district of Queensland. Before harvest, the maturation of individual growers' crops was monitored by subsampling once to twice a week and determining the rate of accumulation of total solids. Harvesting was initiated when the crops were judged to be in the range of 13-15% total solids content.

It had been planned to process all fruit through a single postharvest handling plant newly installed on one of the properties. The plant is designed to phase fruit through the following postharvest handling procedures:

1. *Destemming/washing* Fruit harvested with long stems are manually destemmed and immediately placed stem end down on a set of mobile rollers. These rollers carry the fruit slowly past a set of spray nozzles which spray water vertically on to the fruit to remove sap.

2. *Hot Benlate Dipping* Fruit then enter a heated tank containing 500 ppm benlate at 52°C and are automatically held under the surface of this solution for 5 min.

3. *Cooling/Prochloraz Treatment* For this trial the line was modified so that fruit then passed through a water drench to cool the fruit and then through a spray of prochloraz (250 ppm at ambient temperature). In this trial prochloraz was applied at 1.4 l/min through each of five spray nozzles, fruit being exposed to this spray for approximately 5 sec.

* Queensland Department of Primary Industries, Sandy Trout Food Preservation Laboratory, Hamilton, Queensland 4007, Australia.

4. *Drying/Sorting* Fruit then passed under a fan using ambient air to dry the fruit, then across sorting tables where poor quality fruit were removed.

5. *Sizing/Packaging* Fruit finally passed through a computer-controlled weight grading system which automatically sorted the fruit by size which were then packaged in waxed fibreboard packages.

The three growers supplying fruit, Gosper, Nucifora, Bartlett, are specified by name to facilitate describing the methods employed and the results achieved.

Fruit from the Bartlett and Nucifora properties were harvested with stems 7–15 cm in length into picking buckets and transported to the packing machine where destemming took place. Fruit from the Gosper property were harvested without stems, washed in the property's packing shed and then transported in picking buckets to the main packing plant (on the Bartlett property).

Fruit were processed through the packing plant in the following grower order: Gosper, Nucifora, Bartlett. Fruit temperature at the start of the packing operation was approximately 25°C. On leaving the hot benlate dipping tank pulp temperature was approximately 44°C. The water drench dropped this to approximately 35°C and the fruit reached approximately 32°C on leaving the prochloraz spray.

Problems developed in the line towards the end of the packaging operation. The hot benlate dipping tank was unable to maintain temperature due to the volume of fruit being passed through it. While the final 50% of fruit from the Bartlett property were going through the line, the dip temperature averaged 47°C finally reaching 46.2°C with the last of the fruit.

During the packaging operation some fruit from the Bartlett property were packed in cartons containing plastic 'Plix' inserts, a packing aid made from polypropylene containing indentations or cups for each individual fruit. Other fruit were packed on to an absorbent pad, known as a Jiffy pad, and the rest on expanded polystyrene netting. All other growers were packed onto the latter material. The different packing materials were used to obtain some initial indication of their potential for preventing sapburn.

Following packing, fruit were transported by road to a cool room for precooling. The cool room that had to be used was running at 11°C although the

thermostat setting was at 8°C. No forced air cooling was possible because pallets were not stacked to the full height of the metal angle strips used on the pallets and hence pallets could not be sealed by a top covering sheet to make a unit suited to forced air cooling. On removal from the room the following morning pulp temperatures were 18–19°C. Fruit were loaded into a refrigerated road transport and carried to Brisbane, arriving in approximately 36 hours. Fruit were then placed in a conventional cool room and held overnight before stacking into a CA shipping container. On loading, pulp temperature was then 12°C.

The container was set to provide a storage atmosphere of 5% oxygen and 1% carbon dioxide at 13°C. A difficulty with the scrubbing system resulted in the fruit having to be twice returned to air storage, for a total of 7 days of the storage period of 18 days. Because of marketing requirements, it was finally decided to remove fruit from the container after 18 days instead of the 21 days initially planned. At the time of removal the fruit had been harvested a total of 21 days.

On removal, three cartons of each of five weight grades were removed from each grower's consignment for quality evaluation. Each of the fruit in these cartons was evaluated for external colour, anthracnose and stem end rot development. In all assessments only one assessor was used. External colour was rated on the following scale:

- 1 = surface fully green
- 2 = tinge of yellow colour
- 3 = 1/4 of the surface yellow in colour
- 4 = 1/2 of the surface yellow in colour
- 5 = 3/4 of the surface yellow in colour
- 6 = surface fully coloured.

Severity of anthracnose and stem end rot development in each fruit were both rated using the following scale:

- 1 = nil
- 2 = slight development — insufficient to affect immediate saleability
- 3 = moderate development — sufficient to influence saleability
- 4 = severe development — fruit now not marketable.

A further six cartons containing plastic plix inserts and six containing Jiffy pads were removed from the Bartlett consignment. Another six cartons containing expanded polystyrene netting were also removed from each of the other two growers. Due to an oversight, no cartons using this type of insert

were removed from the Bartlett consignment. These cartons were then used to try to establish the effects of the different inserts on sapburn development and differences in sapburn development between the three growers.

Each fruit in every carton was examined to establish to what extent sapflow continued after packaging. The fruit was examined from the stem end and an assessment made of the percentage of the visible surface area that had come in contact with sap. The rating scale used was:

- 1 = nil
- 2 = 1-10%
- 3 = 11-20%
- 4 = 21-30%
- 5 = >30%

At the same time the amount of sapburn visible was also scored using the same scale, and the intensity of the sapburn also rated as light, medium or severe. These sapburn scores and intensity ratings were then combined to produce a total sapburn score according to the following scale:

- 1 = nil
- 2 = 1-10% of surface showing light intensity burn
- 3 = 1-10% of surface showing moderate intensity burn
- 4 = 1-10% of surface showing severe intensity burn
- 5 = 11-20% of surface showing light intensity burn
- 6 = 11-20% of surface showing moderate intensity burn
- 7 = 11-20% of surface showing severe intensity burn
- 8 = 21-30% of surface showing light or moderate intensity burn
- 9 = 21-30% of surface showing severe intensity burn
- 10 = >30% of surface showing sapburn.

Results

At harvest, the total solids content of the fruit from each of the growers was as follows: Nucifora 12.9%, Bartlett 15.2% and Gosper 15.5% (Table 1). So the fruit from the first of these growers were the most immature, with the other two growers being virtually the same.

Colour and rot development on removal is also shown in Table 1. On removal from storage fruit had just commenced colour development, Nucifora's fruit being slightly more backward than the other two growers reflecting its relative immaturity (lowest TS%). Anthracnose development was virtually zero, confirming the effectiveness of prochloraz in controlling this disorder. However, very high levels of stem end rot were encountered with significant differences ($P < 0.05$) between growers. Although the degree of development was only slight (averaging 1.21-1.64) on removal, rapid subsequent development of the disease was then expected and did occur. The occurrence of this disease suggests that either the hot benlate treatment was not effective against this disease or alternatively there was a failure in the method of application.

That differences between growers did occur is of interest. Possibly the most likely explanation is that the results represent a difference in natural levels of inoculation on the three farms. The Bartlett property (the lowest level) is a relatively new farm just coming into production, and has perhaps had little opportunity yet to develop a high incidence of this disease. The Gosper farm on the other hand has the oldest trees and has had considerable opportunity for high inoculation levels to develop. Tree development on the Nucifora property is intermediate between the other two. The very high level that occurred in Gosper's fruit may also result from the fact that their fruit was destemmed in the field. There is some evidence that the presence and length

Table 1. Colour development and anthracnose and stem end rot development following CA storage for 18 days (total solids data shown for ease of reference). (Figures followed by different letters are significantly different, $P < 0.05$.)

Grower:	Nucifora	Bartlett	Gosper
Total solids (%)	12.9	15.2	15.5
No. fruit examined	245	271	236
Mean colour scores (1-6 scale)	1.98a	2.25b	2.12ab
Incidence of anthracnose (%)	0.4	0.7	0.8
Mean anthracnose score (1-4 scale)	1.008	1.016	1.012
Incidence of stem end rot (%)	29a	14b	66c
Incidence of stem end rot (%/ carton)	29.7a	15.1b	52.7c
Mean stem end rot score (1-4 scale)	1.35a	1.21b	1.64c

Table 2. Relationships between fruit size (count) and colour development and incidence of stem end rot. Data shown are the mean scores across all growers.

Fruit Count:	12	14	15	16	18	20
Mean Colour scores (1-4 scale)	2.14	2.16	2.09	2.10	2.16	2.07
Mean Stem End Rot Development (%)	58.3	29.8	31.1	23.0	27.1	30.6

of stem allowed to remain on the fruit may influence the development of this disease.

Fruit colour on removal was not correlated with fruit size (Table 2), demonstrating that size is not a good indicator of fruit maturity at harvest as more mature fruit at harvest would have had a higher level of colour development on removal. Also stem end rot development does not appear to be related to fruit size. The very high level recorded in the count 12 fruit (58.3%) may, however, be some indication that a slight maturity effect does exist.

On removal from the container the fruit immediately started to ooze sap. Why this occurred is not known. It is apparently a response to the temperature change and probably also reflects the degree of turgidity maintained in mangoes when held in the high humidity of a CA environment. This loss of sap continued for at least 24 hours (Table 3).

While such sap is not injurious to the fruit, i.e. will not cause sapburn, it does mix with water condensing on the fruit and makes the fruit sticky. It tended to collect more within the plix trays. With the Jiffy pads and polystyrene net packing material, it tended to make these materials stick to the fruit so that when the fruit was removed from the packing material pieces of it remained attached to the fruit. The amount of sap that flowed was significantly less on Nucifora's fruit. This may be a reflection of the greater immaturity of the fruit from that grower.

Sapburn development (Table 4) was significantly greater in Gosper's fruit. Gosper was the only grower to harvest without stems and it is believed this is probably the reason for them having a higher level of sapburn. The data show no apparent difference in sapburn due to the different types of inserts that were used. This cannot be taken as a

Table 3. Sapflow following storage. Data shown are the mean scores (1-5 scale) obtained on each of six cartons from each of three samples of fruit from two growers, on removal from storage and again one day later.

Grower sample	Carton No.	On removal	Removal + 1 day
Bartlett (Plix insert sample)	1	2.06	3.06
	2	1.59	2.28
	3	1.56	1.83
	4	2.00	2.29
	5	1.56	2.00
	6	1.67	1.78
Mean		1.74	2.21
Bartlett (Jiffy Pad Sample)	1	1.39	1.44
	2	1.61	1.78
	3	1.94	2.67
	4	1.64	1.86
	5	1.78	1.78
	6	1.78	2.06
Mean		1.69	-1.93
Nucifora (Polystyrene Net)	1	1.25	-
	2	1.00	-
	3	1.33	-
	4	1.13	-
	5	1.22	-
	6	1.28	-
Mean		1.20	-

Sapflow on removal < sapflow on removal + 1 day ($P < 0.05$).

Sapflow Nucifora < sapflow Bartlett ($P < 0.05$).

Table 4. Variation of sapburn in relation to grower and carton insert. Data shown are the mean scores (1–10 scale) obtained on each of six cartons within each grower sample.

Grower: Insert:	Sapburn scores (1–10 scale)			
	Bartlett Plix tray	Bartlett Jiffy Pad	Nuciflora Polystyrene Net	Gosper Polystyrene Net
Carton No.				
1	1.67	1.67	2.00	3.22
2	1.24	1.78	1.88	3.27
3	1.33	1.00	1.78	2.44
4	1.33	2.28	2.25	3.37
5	1.89	1.94	1.72	2.94
6	1.33	1.61	1.83	1.95
Mean	1.47	1.71	1.91	2.87

Sapburn Gosper > other three samples ($P < 0.05$).

confirmed result since data were not collected on the different inserts within the one grower's fruit. In examining Table 4, it should also be noted that while the sapburn scores depicted represent a low level of injury, the degree of burn could still be sufficient to detract slightly from fruit marketability.

Discussion

This trial has demonstrated that when mangoes are harvested at an appropriate degree of maturation, their storage and transport within a CA container for 3 weeks is commercially feasible. In this trial ripening was significantly delayed in spite of the fact the fruit were not under full atmosphere control for the whole period. In fact ripening was retarded to such a degree that a considerably longer storage period would have been feasible.

The problems that developed with carbon dioxide control within the container were primarily due to the efficiency of the scrubbing system employed. They in no way reflect on the viability of this type of

technology, but do indicate that improvements within the scrubbing system are required.

The level of stem end rot encountered was unexpected, and ultimately resulted in the loss of a considerable quantity of the fruit used in the trial. However, laboratory studies are still confirming the efficacy of the rot treatment that was applied, and it is believed the result was brought about by some failure or inadequacy within the system used to apply the hot benomyl treatment. Once the disease was able to occur, other factors such as spore load, destemming, inadequate cooling and failure to maintain the CA conditions for the full storage period all contributed to the degree of development that eventually occurred.

Acknowledgment

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Disinfestation of Durable Foodstuffs in ISO Containers Using Carbon Dioxide

H.J. Banks *

CONTAINERS are widely used for transport of durable commodities such as grains, flour, pelleted animal feeds, timber and hay. These commodities may be infested with insects and other pests and usually require a disinfestation treatment, to comply with various import, export and quarantine regulations, if they are being traded internationally.

Containers and containerised cargoes provide a particular quarantine hazard (Freeman 1968) to countries at present free of particular species or critical strains of pests, as both the load and the container fabric itself are capable of carrying pests. Also containers may be taken from agricultural areas in one country directly to another without 'unstuffing' (removal of the cargo).

The range of disinfestation treatments for containers is very limited. At present fumigation is the only process available that can be used to disinfest a container and contents completely, and only methyl bromide and phosphine are in common use as fumigants. Both have properties that make their use inconvenient or unacceptable in particular situations. Methyl bromide is toxic to humans, requires trained and, in many countries, licenced applicators, and leaves residues in the commodity. Phosphine is very toxic to humans and its use is restricted by regulations and industrial requirements. Furthermore, strains of insect pests resistant to phosphine now occur in some countries (Tyler et al. 1983). Spread of this resistance would further restrict phosphine use. There is a clear need for alternatives to these two fumigants. Use of CO₂ may be one such alternative. Current knowledge on CO₂ for dis-

infestation of containers, recommendations for its use and limitations are summarised in this paper. The data and discussion refer to 20 ft (6.1 m) ISO containers filled with grain or similar durable foodstuff. Much of the basis for CO₂ use given here has been laid by collaborative research by CSIRO Divisions of Entomology and Food Research, in conjunction with other government agencies, container companies and exporters. Salient results from this research are used to illustrate particular features of the technology of CO₂ application and its development to a well-founded process, ready for commercial use.

Background

Several interrelated topics needed research during the development of CO₂ as a disinfestant for containers. These were:

- (a) the concentration-time regime required
- (b) the forces controlling gas loss from containers
- (c) quantification of gastightness of containers
- (d) methods of adding CO₂
- (e) dispersion of CO₂ through containerised cargo
- (f) level of gastightness permitting effective CO₂ use
- (g) techniques for improvement in gastightness of containers.

Concentration-Time Regime Required

CO₂-rich atmospheres are known to be lethal to most stored product pests (Bailey and Banks 1975,

* CSIRO Division of Entomology, GPO Box 1700, Canberra, ACT 2601, Australia.

Table 1. Experimental treatments of infested container loads with CO₂.

Location	Load	Initial CO ₂ concentration ^a %	Concentrations (%) at end of exposure	Exposure period (days)	Load temperature (°C)	Species ^b	Mortality	Infestation ^c	Reference
Cunningar, NSW	Wheat	68	44	4.5	22	SO	survival	bioassay	Banks, H.J., and Sharp, A.K. (unpublished data)
Rabaul, Papua New Guinea	Copra	74	45	6	25	NR OM	complete complete	natural natural	Banks, H.J., and Annis, P.C. (unpublished data)
Sydney – Hamburg ^d	Wheat	45	50	10+ ^e	26	SO RD	complete complete	bioassay natural	Banks and Sharp (1979)
Melbourne – Yokohama (6 containers) ^d	Malt	>54	>10	16+ ^e	36	SO TC	complete complete	bioassay bioassay	Banks and Annis (1980)
Lae – Sydney ^d	Coffee	c.65	36	17	c.28	SO TC	complete complete	bioassay bioassay	Sharp and van Greve (1985)
Lae – Sydney ^d (2 containers)	Coffee	c.90	5	19	c.28	TC SZ	complete survival	bioassay bioassay	Sharp and van Greve (1985)
Rabaul – Melbourne ^d	Cocoa	82	36	10+ ^e	28	TC SO	complete complete	bioassay bioassay	Sharp and Greve (1981)
Rabaul – Melbourne ^d	Cocoa	79	57	10+ ^e	28	TC SO	complete survival (<1:3000)	bioassay bioassay	Sharp and Greve (1981)
Lae – Sydney ^d	Coffee	50	20	10+ ^e	28	TC SO	survival survival	bioassay bioassay	Sharp and Greve (1981)
Lae – Sydney ^d	Coffee	58	60	10+ ^e	28	TC SO	complete complete	bioassay bioassay	Sharp and Greve (1981)

^a After sublimation of initial loose charge.

^b SO = *Sitophilus oryzae*, NR = *Necrobia rufipes*, OM = *Oryzaephilus mercator*, RD = *Rhyzopertha dominica*
TC = *Tribolium castaneum*, SZ = *Sitophilus zeamais*.

^c Bioassays were caged insects and contained all developmental stages (> 1000 insects per container).

^d In-transit trial.

^e Not vented until end of voyage, CO₂ levels may still be substantial after end of nominal exposure period.

1980; Annis, in press). These include various species of insects, mites and rodents. Snails, sometimes associated with durable commodities in containers, are also affected. Susceptibility to CO₂ varies widely with pest species and developmental stage. Some are highly susceptible. Rats and mice die with exposures of only a few hours to 25% CO₂ (Cornwell 1979). Most stages of most stored product insect pests are eliminated by exposures at >35% CO₂ for 10 days (Banks 1979). However, some developmental stages of some important species are very tolerant, requiring >60% CO₂ for >10 days for complete kill. These tolerant pests include diapausing larvae of *Trogoderma granarium* (Spratt et al. 1985) and aestivating Mediterranean white snail (*Ceruella* spp.) (Annis, P.C. and Banks, H.J., unpublished data). Response data for larvae of the wood-boring insect *Hylotrupes bajulus* and *Sirex noctilio* (Paton and Creffield, in press) suggest that some may also survive this exposure.

The current recommended target CO₂ regime for disinfestation of containers is that an initial concentration of >60% be generated and that >35% CO₂ be present after 10 days (Sharp and Banks 1980). This regime is generally supported by the results obtained in both static and in-transit trials carrying bioassays or heavy natural infestations (Table 1) and is similar to that given by Banks (1979) for treatment of static grain bulks. Furthermore, there have been no reports of infestation on outturn from commercial shipments of grain CO₂-treated to meet this regime. However, there have been insufficient well-monitored trials to give a good measure of the failure rate to be expected when the regime is just attained. Thus it must still be treated as provisional, pending further results in commercial use.

The most appropriate exposure to CO₂ remains the major area of uncertainty in the development of CO₂ disinfestation of containers. Recently obtained results from laboratory studies suggest that the regime, >60% initially and >35% after 10 days, may not be quite sufficient to eliminate some developmental stages of *Sitophilus* spp. (Annis, in press), though in the absence of *Trogoderma* larvae it is adequate for elimination of other common stored product pests. Indeed survival of a single immature *Sitophilus* was noted under an apparently adequate concentration regime in a container trial (Rabaul - Melbourne, Table 1). However, in view of the general success of the present recommendation there does not appear to be a need for a more stringent one at this time. There is an adequate

understanding of how to attain specified CO₂ regimes (see below) for the appropriate adjustments to dosage recommendations to be easily calculated if required.

Forces Controlling Gas Loss from Containers

There are several environmental forces that cause gas to be lost from within a container and to be replaced with air. These forces typically give rise to an exponential fall in concentration of a gas such as CO₂ (Fig. 1) (for relevant formulae, see Appendix

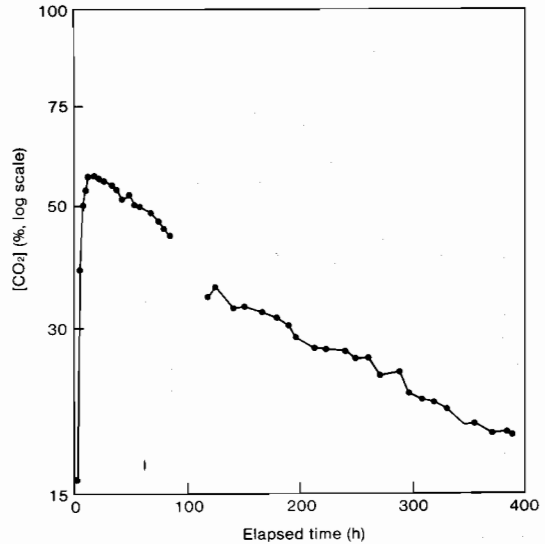


Fig. 1. Fall in CO₂ concentration with time in a well-sealed container of wheat (18 t) charged with 40 kg dry ice (Banks, H.J., and Sharp, A.K., unpublished data). Break in curve corresponds to time in transit on rail.

1). The important forces causing gas loss are wind, rate of ascent while in transit, internal (headspace) changes in temperature and variation in barometric pressure. A mathematical model has been developed to describe the quantitative effect of the various forces (Banks and Sharp 1986), predicting the individual contributions to the overall loss rate constant, k (see Appendix II). In practice, the loss of methyl bromide and carbon monoxide from container atmospheres are both well described by the model (Banks et al. 1986). Presumably loss of CO₂ can be similarly modelled.

If the concentration-time regime, >60% initially, >35% CO₂ after 10 days, is to be met, k , the loss rate constant, must be <0.054/day unless a source of gas is provided during the holding period. Predic-

Table 2. Rate constants for loss per day produced by various factors under different conditions as predicted by the model of Banks and Sharp (1986).

Factor	Magnitude	Static		In-transit	
		Leaky ^a	Well-sealed ^b	Leaky ^a	Well-sealed ^b
Internal temperature variation	10°C cycle per day in headspace	0.024	0.024	0.024	0.024
Barometric pressure variation	1000 Pa per day	0.010	0.010	0.010	0.010
Wind and transport velocity	Wind 2 m/sec Transport 8 m/sec	0.43	0.029	1.74	0.11
Ascent and descent	Ascent 6 m/sec over 3 in 1000 grade	—	—	0.19	0.19
Sum of individual effects <i>k</i>		0.46	0.063	1.96	0.33

^a 'Leaky' – pressure decay half life (250–125 Pa) 2 sec, $Q_5 = 182 \text{ m}^3/\text{day}$.

^b 'Well-sealed' – pressure decay half life (250–125 Pa) 15 sec, $Q_5 = 12 \text{ m}^3/\text{day}$.

ted individual loss rate constants for the dominant forces causing gas loss are given (Table 2) for leaky and well-sealed containers under static conditions and in transit. The parameter values used for calculation are typical for Australian conditions. Much greater values may sometimes occur though usually only briefly and having little effect on *k*, when averaged over a period of a day or more.

It can be seen from Table 2 that even in the best case given, static and well-sealed, the predicted value of *k*, the sum of the individual contributions, exceeds 0.054/day. Thus the target regime will not be met by a single charge of CO₂ gas. Furthermore, under leaky conditions, even light winds (2 m/sec) cause substantial gas loss. The problem is exacerbated by transportation since this gives an added air velocity over the containers. Ascent and descent cause particular problems. Passage over hilly terrain causes much gas loss through the pumping action of the changes in barometric pressure with altitude.

The model sets out explicitly the reasons (1) why, in practice, it is necessary to provide a source of CO₂ gas within the container to replenish the CO₂ atmosphere if the target concentration-time regime is to be met, and (2) why transport of containers on land under gas causes substantial losses. Furthermore it is apparent that containers must be well sealed to have a leak rate constant close to that required even under static conditions. Figures 1 and 2 show the increase in loss of gas caused by

transportation and an example of CO₂ loss during transit over hilly terrain and the contributions of changes in temperature and pressure to that loss. It can be seen that these changes are responsible for most of the loss observed and that the substantial drops in pressure resulting from crossing mountain ridges cause major falls (Fig. 2).

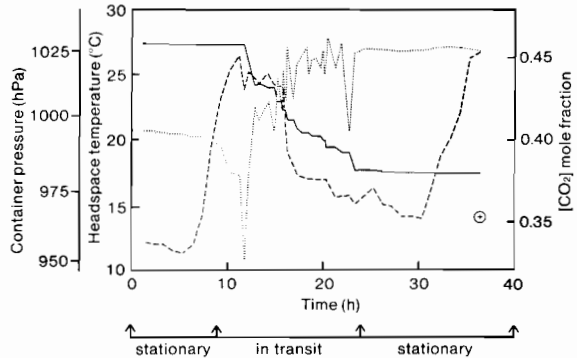


Fig. 2. Changes in barometric pressure (.....) and temperature in the headspace (-----) in a well-sealed container, load 18 t wheat, stationary and in transit on rail, with calculated fall in CO₂ concentration caused by these factors (—) and the observed CO₂ concentration (⊙) at the end of the journey (Banks, H.J., and Sharp, A.K., unpublished data).

Consideration of the effects of the forces causing gas loss highlights the need to carry out in-transit

tests when developing gas processes for containers. Good performance in static trials is a necessary but not sufficient condition for success. Furthermore tests in-transit on land are likely to be more exacting than by sea since, in the latter case, temperature variation is much reduced and there are no losses from changes in altitude.

Quantification of Gastightness

Containers vary widely in their gastightness. Some are built to a gastightness specification (e.g. reefers, bulk containers; see Sharp et al. 1986) but general purpose containers, the type most readily available, are not. Most appear to be well sealed on inspection, but when tested are frequently found not to be so.

Two objective test procedures are available for measuring gastightness: the steady state test and the pressure decay test (Banks 1984). In the former, air is introduced into the container at various known rates and the equilibrium pressure generated is observed. The variation of pressure with flow gives a measure of gastightness. In the pressure decay test gastightness is related to the time taken for an excess internal pressure to decay to a proportion, usually half, of the initial value. The steady state test is more complex and slower to carry out than the pressure decay test but is more informative. The two tests can be correlated (Appendix I).

It has been shown both theoretically (Banks and Sharp 1986) and in practice (Banks et al. 1986) that pressure test results provide a measure of the susceptibility of a container to gas loss caused by wind and transport velocity. Furthermore the effect of wind and transport velocity may be so great with leaky containers that there is little chance that the target exposure regime will be achieved. A machine, the Contestor, has been developed (Sharp 1982) for selecting containers, using the pressure decay test, on the basis of their gastightness. Inadequately sealed containers can be rejected or treated before filling or otherwise expending unnecessary effort.

Addition of CO₂ to Containers

CO₂ may be added to containers either as dry ice, as liquid forming 'snow' or as gas from cylinders. All but two of the trials carried out to date have used dry ice, even though this is a more expensive source of CO₂ than cylinders or liquid, as it is simpler to apply and a supply of dry ice is required in any case

to maintain adequate gas concentrations (see below).

The peak CO₂ concentration resulting from a given charge of CO₂ can be calculated (see Appendix I). There appears to be little difference between the different CO₂ sources in terms of efficiency of purging and the observed concentrations are distributed evenly about the theoretical curve (Fig. 3). To be sure of attaining a given concentration in the 40–70% CO₂ range, about 40% more CO₂ than theoretically is required (Fig. 3).

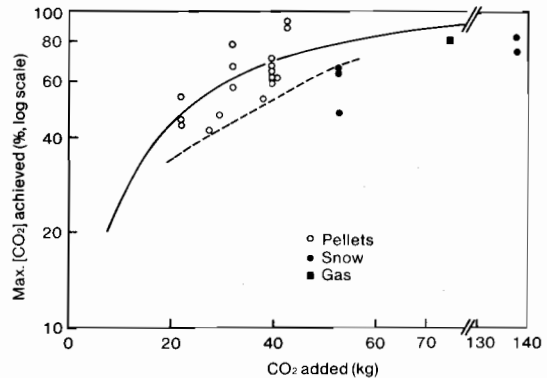


Fig. 3. Peak concentration of CO₂ achieved from various dosages. From Sharp and Banks (1980) with added data from Sharp and Greve (1981) and H.J. Banks and A.K. Sharp (unpublished data). Quantity added includes an allowance for gas liberated from slow release box, where used. Solid line, theoretical; broken line, theoretical with 40% additional charge.

The target CO₂ regime cannot be met reliably with containers of normally available gastightness using a charge of CO₂ that all volatilises rapidly, as there is no buffer stock of CO₂ to compensate for short periods of high rates of gas leakage. This is clear both from practical experience and modelling studies. Loose dry ice volatilises over a few hours (Fig. 4) and thus an alternative source of gas is required. This problem has been overcome using an insulating box containing dry ice as part of the CO₂ charge. The box restricts the rate of volatilisation, providing a continuous addition of CO₂ gas over a period determined by the heat transfer qualities of the insulation. A box made of 75 mm expanded polystyrene foam, containing >30 kg dry ice, maintains a continuous output over 10 days (a '10-day' box) (Sharp and Banks 1980). The corrugated cardboard boxes used for shipping block dry ice give a 4-day output period (Banks and Annis 1981). This shipping box contains a 22-kg block wrapped in

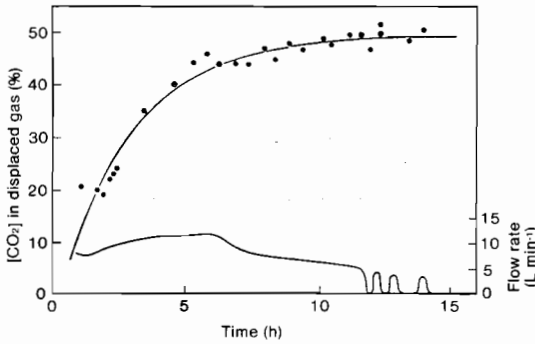


Fig. 4. Flow rate of (lower line) and CO₂ concentration in (upper line) gas displaced from a container, load 18 t wheat, during sublimation of a charge of 30 kg loose dry ice pellets (Banks, H.J., and Sharp, A.K., unpublished data).

several layers of newspaper. Polystyrene picnic baskets ('Esky') of about 25 mm thickness with 40 kg dry ice provide about 5 days of output (Sharp and van Greve 1985).

The cardboard shipping boxes gave an adequate level of insulation and output in shipping trials of malt to Japan under CO₂ (Banks and Annis 1981), but 25 mm thick polystyrene boxes did not provide sufficient insulation in a trial with cocoa and coffee from Papua New Guinea (Sharp and van Greve 1985). The two containers used in the latter trial, though still quite well sealed (200–100 Pa, 19 sec

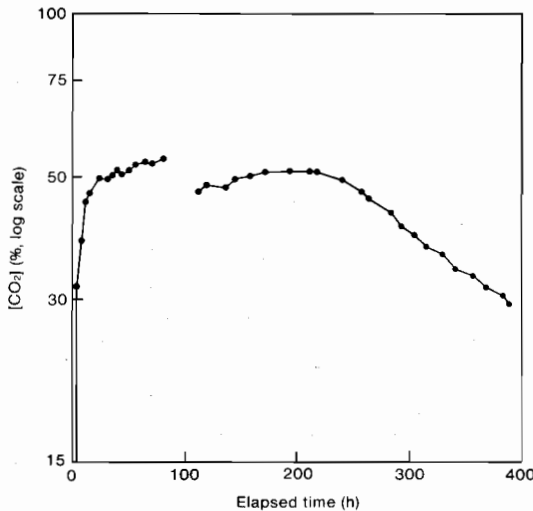


Fig. 5. Fall in CO₂ concentration with time in a well sealed container of wheat (18 t) charged with 30 kg dry ice, loose, and 30 kg dry ice in a '10-day' insulating box (Banks, H.J., and Sharp, A.K., unpublished data). Break in curve corresponds to time in transit on rail.

and 29 sec), were more leaky than the six used in the malt trial (all >48 sec). More dry ice was used in the boxes in the first trial (44 kg, second trial 30 kg). These differences may account for the difference in outcome. Boxes of 75 mm polystyrene can maintain adequate concentrations of CO₂ even against the heavy losses resulting from transportation on land (Fig. 5).

Table 3. Theoretical dosing schedules meeting the target regime (>60% CO₂ initially, >35% after 10 days) with $k = 0.18/\text{day}$ and load 18 t grain.

Loose dry ice (kg)	Dry ice in box (kg)	Time for sublimation from box (days)
33	30	10
30	60	7
35	145	5

The use of a 10-day box with 33 kg dry ice loose and 30 kg in the box increases the maximum loss rate constant, k , that still permits the target regime to be met from 0.054 to 0.18/day. If boxes giving a higher sublimation rate are used the quantity of CO₂ required to meet the target regime increases substantially (Table 3).

Dispersion of CO₂ Through a Container

CO₂ disperses rapidly when added as dry ice to the surface of a wheat bulk in a container. Concentrations throughout become almost uniform within a few hours of completion of volatilisation of the charge (Fig. 6) and remain so during the exposure

Door end			Centre			Front end		
			Liner	66				
			Head space	67				
			Load	74				
67	65	67		74			72	71
61	68	64		69	71	70	67	71
								68

Fig. 6. CO₂ concentrations (%) in a container with a polyethylene liner, load 18 t wheat, 20 hours after closing, with 30 kg loose dry ice pellets at door end (Banks, H.J., and Sharp, A.K., unpublished data).

period. CO₂ has been observed to penetrate easily bagged wheat (Banks, H.J., and Sharp, A.K., unpublished data), copra (Banks, H.J., and Annis, P.C., unpublished data) and cardboard packing (PAL) boxes of cocoa and coffee (Sharp and Greve

1981) in containers when the charge is added to the surface of the stow.

If CO₂ is added as dry ice at floor level, stratification of the gas occurs and regimes of inadequate CO₂ are obtained in the higher parts of the stow (Sharp and Greve 1981). Presumably CO₂ added at the floor as gas or snow will behave similarly, except that the velocity of addition may cause some mixing.

Acceptable Level of Gastightness

A gastightness corresponding to a pressure decay test time of >10 sec (200–100 Pa) appears adequate to retain CO₂ in a stationary container above 35% for more than 10 days, given a '10-day' slow release box with 30 kg CO₂ and a 30 kg initial charge (Sharp and Banks 1980). Figure 7 shows the gas

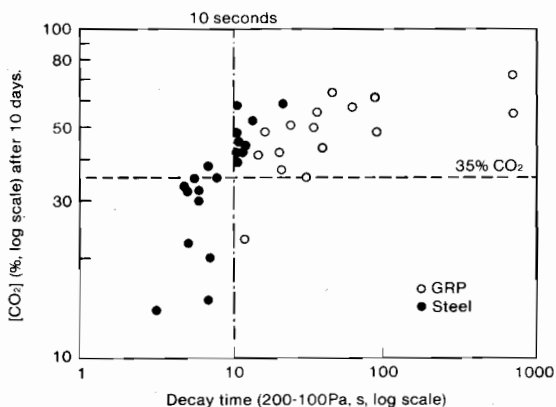


Fig. 7. CO₂ level present after 10 days as a function of pressure decay test in either static steel or glass-reinforced plastic containers, load 18 t wheat, CO₂ added, 30 kg loose with 30 kg in a '10-day' box (redrawn from Sharp and Banks 1980).

retention in general purpose containers containing 18 t bulk wheat as a function of pressure test. The level of gastightness required will depend on environmental conditions and particularly whether the container is subject to a long land journey while under gas. Increasing the initial dosage of CO₂ has little effect on whether the target is met at 10 days, though it increases the likelihood of achieving the required initial concentration. A standard of a 10 sec decay time has been found acceptable in all steel general purpose containers studied to date but there are insufficient data on performance close to this standard to give an estimate of how often it is inadequate. Only one of 16 containers made with glass reinforced plastic walls and roof failed to

retain >35% after 10 days. All had decay times of >10 sec (Fig. 7).

Improving Gastightness of Containers

Frequently general purpose containers do not meet the 10 sec pressure decay standard without some modification or repair. In particular plank-floored containers can leak extensively through the floor. None of the 22 plank-floored general purpose containers studied by Sharp et al. (1986) had sealing equivalent to this standard (Fig. 8). About 40%

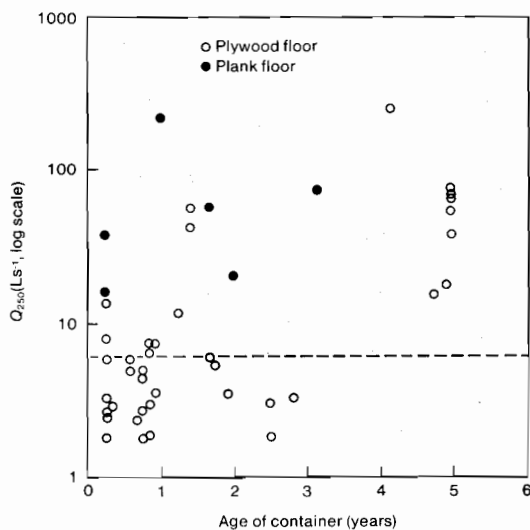


Fig. 8. Leakage at 250 Pa internal pressure as a function of container age for two types of floor construction (redrawn from Sharp et al. 1986). Dotted line represents a 10 sec decay time (250–100 Pa).

of the ply-floored ones also failed initially but only one of the 17 bulk containers did so.

Experiments have been carried out both in Australia (H.J. Banks, unpublished data) and elsewhere (Jay et al. 1983) on how to improve gastightness of poorly sealed containers. In addition to sealing defects in the door seals, walls and roof, some form of complete floor treatment is normally required with plank-floored containers. This entails considerable expense or effort and is unlikely to be commercially feasible. Successful approaches (H.J. Banks, unpublished data) include complete sheeting of the floor with polyethylene sheet, taped to the walls, and application of various coatings (Diathon, Elastuff 730 or Envelon 561/100). Ply-floored general purpose containers usually require little

effort to upgrade to a suitable level of sealing, given intact door seals and no obvious damage. It is normally sufficient to caulk each of the seams around the six sheets of ply forming the floor with silicone rubber sealant or mask them with tape. The wall-to-floor join and corners are usually the major sources of leakage.

Use of plastic film liners appears a promising approach to increasing gastightness. However, Sharp et al. (1986) note that this was not successful as tested because the liners developed leakage through tears made during loading.

Current Recommendations for CO₂ Use

Based on the research results summarised above, the following procedure should provide a CO₂ concentration meeting the regime, where >60% is achieved initially, with >35% remaining after 10 days and with gastightness of the empty container such that the pressure decay time (200–100 Pa) exceeds 10 sec.

After filling the container *either* place at least 40 kg of dry ice (pellets or crushed block) on the top surface of the stow with 30 kg or more of dry ice contained in a closed box of 75 mm medium density polystyrene foam (internal dimensions 500 × 350 × 200 mm) *or* use 40 kg dry ice pellets or crushed block with 60 kg in a closed box of 50 mm medium density polystyrene foam (similar dimensions to above).

The chances of success are maximised by keeping the containers out of sunlight and wind and adding the CO₂ after, not before, transport to the port from up-country.

Limitations to Use and Commercial Acceptance

The process described herein has gained only very limited commercial acceptance. It has been used to export wheat grown for 'health food' markets which does not permit the use of fumigants other than CO₂ or of synthetic insecticides on the grain. About 500 t of lucerne pellets were shipped from Australia in 1986 in containers under CO₂. There is some use on peanuts in containers and the process is under consideration for export hay. It is not feasible to extend the use of high levels of CO₂ to transport and disinfestation of perishables as in

most cases the commodity cannot withstand the CO₂ regime required.

Several factors prevent the process from being more widely adopted in Australia. The main problem appears to be the legal need to present commodities in a pest-free condition at point of export if they come under the Export Control Act, subser-vient legislation and Ministerial orders. Normally this precludes CO₂ as an in-transit disinfestant for use on board ship, except as a precautionary measure. However legislative provisions exist that allow exports not meeting this requirement, subject to specific agreements being established between the Australian Quarantine and Inspection Service and overseas quarantine authorities. Arranging these agreements themselves may be complex and slow. Cost is also important. The cost of the dry ice may be significant, with 70 kg costing about \$A40 when bought in lots of a few hundred kilograms. The slow release box may cost \$A10–15. However, these costs may be similar to those incurred indirectly using the cheaper fumigants, methyl bromide or phosphine. Methyl bromide requires a licenced applicator, and some countries charge for the testing of containers shipped under phosphine for safety at outturn. Finally, the need for well-sealed containers may discourage use of CO₂. It is usually possible to find suitable containers but this may involve additional effort, use of particular types of container, and cost associated with relocation of inadequate ones.

Conclusion

CO₂ use as a disinfestant is now developed to a stage where it can be used commercially. The background physics is understood quantitatively. The dosage rates for CO₂ to meet a set concentration regime suitable for control of pests are known. Limitations in CO₂ use range from regulatory requirements to its inability to control diapausing larvae of the quarantinable pest *Trogoderma granarium*. The advantages include ease of use, lack of residue on commodities and low mammalian toxicity. It is a process waiting for an application.

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Appendix I — Formulae

1. Rate of loss of gas from a container (Banks and Sharp 1986)

The concentration of gas, c , in a container after time, t , is given by:

$$c = c_0 e^{kt} \quad (1)$$

where c_0 is the initial concentration, k is the loss rate constant and no gas is being generated internally.

2. Correlation of pressure tests (Sharp 1982)

In the steady state test the pressure generated within the container, Δp , is related to the input flow, Q , by the formula

$$Q = b \Delta p^n \quad (2)$$

where b and n are empirical constants.

In the decay test, the decay of pressure from the initial level Δp_1 to final Δp_2 over time t is given by

$$\Delta p_1^{1-n} - \Delta p_2^{1-n} = (1-n) b K t \quad n \neq 1 \quad (3)$$

or

$$1n \Delta p_1 - 1n \Delta p_2 = b K t \quad n = 1 \quad (4)$$

where

$$K = \frac{\rho R T}{28 (V - m_{bulk}/\rho_{bulk})} \quad (5)$$

and b and n are as in equation 2.

3. Maximum CO₂ concentration expected (adapted from Banks 1979)

The maximum concentration of CO₂, c_{max} , expected from a charge of CO₂, ${}^m\text{CO}_2$, is given by

$${}^m\text{CO}_2/\rho\text{CO}_2 = (V - m_{bulk}) 1n (1 - c_{max} \cdot 100) \quad (6)$$

4. Expected concentration rise and decay (adapted from Sharp and Banks 1980)

The CO₂ concentration, c , at time t is given by

$$c = \frac{4400 [r - (r - a n_0)] e^{-at}}{(V - m_{bulk}/\rho_{bulk})} \quad (7)$$

where

$$a = r/N + k \quad (8)$$

and r is the rate of sublimation of CO₂ in kg-mol/sec.

Appendix II – Notation

b, n	empirical constants
c	CO ₂ concentration
k	gas loss rate constant
m	mass
n	moles of CO ₂ present
p	difference in gas pressure between container and external
r	rate of sublimation (kg-mol/sec)
t	elapsed time
K	a constant as defined in equation(s)
N	total moles of gas present
Q	gas input rate
R	universal gas constant
T	absolute temperature
V	container volume
ρ	density (true not bulk density)

Subscripts

0	initial
1	first reading
2	second reading
5	at SPa
bulk	relating to load
Max	maximum
CO ₂	relating to CO ₂

In-Container Cold-Disinfestation of Fruits and Vegetables

Alister K. Sharp*

UNTIL now, fruit exported to parts of the world requiring security against fruit fly was fumigated with EDB (ethylene dibromide) before leaving Australia. Ethylene dibromide fumigation is rapid and cheap, and can be applied in the container after loading for export. Now, however, EDB is suspected of being carcinogenic, and consequently its use with foodstuffs has been banned by the United States Food and Drug Administration, and most countries are phasing out its use. No other safe chemical disinfestation treatments are available to replace EDB fumigation, leaving only the physical treatments of irradiation and cold-disinfestation for disinfestation of Australian horticultural exports.

Low-dosage irradiation was approved recently by the FAO/WHO Codex Alimentarius Commission for uses that include fruit fly treatment, and it is also a suitable quarantine treatment for other pests. Irradiation is a rapid process, but the equipment required is expensive, and therefore difficult to justify for a seasonal demand. There will always be additional transport and handling costs associated with irradiation, and there will probably be consumer resistance to its use, especially for produce destined for Japan, which is one of the most promising new markets for Australian citrus fruits.

The alternative technique, cold-disinfestation, is a simple physical process which, at little additional expense, can be applied to produce which is to be stored or transported under refrigeration. Cold-disinfestation consists of prolonged exposure to temperatures near 0°C, the duration depending on temperature and on the species of fruit fly for which

the treatment is intended. Eggs and adult flies are killed by exposure to low temperatures, and larvae are sufficiently damaged to prevent them from developing into adults. Most countries which specify quarantine treatment of imports against fruit fly (Higgs 1983) follow the US requirements (Anon 1985) which are summarised in Table 1. Recent

Table 1. Time-temperature regimes specified for cold-disinfestation of fruit imported into the United States.

Maximum temperature during treatment period (°C)	Period of treatment required (days)	
	Mediterranean fruit fly	Queensland fruit fly
0.0	10	13
0.6	11	14
1.1	12	18
1.7	14	20
2.2	16	22
above 2.2	not permitted	not permitted

unpublished studies of Queensland fruit fly by C.J. Rigney at the Gosford Horticultural Postharvest Laboratory suggest that these times can be shortened; for example, effective treatment against Queensland fruit fly was achieved by 16 days below 1.5°C.

At these low temperatures, the fruit must be protected against freezing. The freezing point of oranges depends on many factors, including the variety and sugar content, and can be as high as -1°C. Cold-disinfestation, then, involves holding produce for periods of 2-3 weeks, with temperatures remaining between -1 and +2°C throughout the stow during the whole treatment period.

* CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113, Australia.

The temperature regime needed for cold-disinfestation is most easily achieved in a cool-store, using, if necessary, additional fans to increase the rate of air circulation (e.g. as described by Watkins 1985 for forced-air cooling). But cool-store treatment involves additional handling, expense and delay. An alternative is to incorporate the cold-treatment into the transport system. If shipped in a conventional refrigerated ship, the treatment could be applied during the voyage, but most of our horticultural exports are carried in containers. An in-container treatment could be applied either before or during the voyage. Containers are smaller than cool-stores or the hold of a conventional ship, and therefore have the inherent disadvantage of having relatively large rates of heat leakage through the walls. This makes it difficult to keep temperatures uniform throughout the load, and throughout the treatment period.

A problem with any form of cold-treatment is that to satisfy quarantine authorities, fruit temperatures must be monitored throughout the treatment period; if even a single reading is above the specified maximum, the treatment period must be recommenced from when the temperature is reestablished. With pretrip treatments, this might result in the container missing the ship, and with in-transit treatments, it could result in delays and added costs to repeat the treatment after arrival. The cold-disinfestation procedure, therefore, should be carefully designed to ensure success.

There are two basic types of refrigerated container, porthole containers and integral containers, which differ in the source of refrigeration, and in the environment in which they are carried on board the ship:

Porthole containers are simply insulated, are supplied with temperature-controlled air, and are carried by 'cellular' container ships. Most produce exported from Australia to Europe and the USA is carried in porthole containers. On board ship they are stowed below deck in cooled holds, and are cooled with air from a central refrigeration system. Precise control of temperatures is possible, and, because this system is centralised, container temperatures can be supervised continually by the ship's engineers. On shore, porthole containers receive chilled air from individual 'clip-on' refrigeration units, or from 'tower-units,' and behave similarly to integral containers.

Integral containers each incorporate an individual electrically powered refrigeration unit. Pro-

duce exported to Southeast Asia and to Japan is carried in integral containers on roll-on-roll-off (ro-ro) ships. The containers may be stowed either above or below deck, but in both these locations air temperatures can exceed 35°C in the tropics. The sources and movements of heat in an integral container are shown in Fig. 1. Such high temperatures

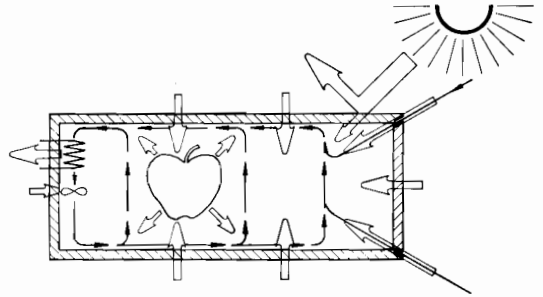


Fig. 1. Heat load on a bottom-delivery integral container, includes the heat of respiration, heat leakage through the walls and doors, radiant heat, and the heat equivalent of the fan power.

increase the rate of heat leakage through the container walls tenfold compared to a porthole container in a conditioned hold, as shown in Table 2, and the high temperatures can also affect the calibration of the refrigeration unit's temperature control system. Moreover, the operation of the

Table 2. Calculated heat loads while in the tropics, in porthole containers carried in a conditioned hold, and in integral containers at 35°C. (Stow temperature 0°C, mass of stow 15 t, heat of respiration 14 W/t, insulation value of container 27 W/°K.)

	Container	
	Porthole	Integral
Ambient temperature (°C)	2-5	35
Heat of respiration (W)	210	210
Heat leakage (W)	95	945
Heat load entering through the walls (%)	31	92

refrigeration unit is checked only once or twice each day by the ship's personnel, and not at all in rough weather. Early models of integral container, many of which are still in use, were intended primarily for frozen foods. They have low rates of air circulation (nominally 60 volumes/hour, and often as low as 40) and simple on-off control of the temperature of the return air stream. Most integral containers now being purchased by the shipping lines serving Australia have air circulation rates of 90 volumes/

hour, and for chilled produce the compressor operates continuously, controlling the temperature of the delivery air stream.

Since 1970 apples and pears consigned to the USA in cellular container ships have been treated successfully in transit by cold-disinfestation in port-hole containers, but only because special care has been given to temperature control (Husband 1976). The fruit is precooled to below 2°C before loading into the container, the container temperature is stabilised before being loaded on to the ship, and the voyage is sufficiently long to allow restabilisation of temperatures before the start of the treatment period. The containers are fitted with precision resistance temperature sensors, the hold is cooled to 0°C, and air is delivered to the containers at a temperature between -2.0 and -1.5°C, with the intention of maintaining fruit temperatures below +0.6°C for 14 days. As yet, however, nowhere in the world is in-transit cold-disinfestation practiced routinely in integral containers.

To treat produce in integral containers, the same degree of care must be applied to cooling and monitoring, and the containers must have higher rates of air circulation to compensate for the higher ambient temperatures they experience on board the ship.

A further problem in the cold-disinfestation of subtropical fruits such as oranges is that low temperatures may cause chilling injury. Chilling injury can take many forms; the term includes any disorder which would not develop if the fruit were held at a higher temperature. The most common chilling injury of oranges is the development of small discoloured sunken spots on the skin, although these often are not apparent until some time after removal from storage. Oranges grown in South Australia are more susceptible to chilling injury than those from New South Wales or Queensland; the incidence of injury depends on the variety and the time of harvest, and varies from year to year. The biochemical mechanisms of chilling injury are still unknown, but it is likely that techniques will be developed to prevent it, or at least to select export fruit which will not be affected. For example, it has been shown that chilling injury to Florida grapefruit can be prevented by prestorage conditioning at intermediate temperatures (Hatton and Cubbedge 1983).

A recent investigation at the CSIRO Food Research Laboratory (Sharp et al. 1987) was planned to assess whether cold-disinfestation of oranges is possible in the current series of integral refrigerated containers, whether the fruit can be

loaded without precooling, whether cold-disinfestation could be performed in-transit, and whether the fruit would suffer chilling injury. The requirement in this trial was to maintain the temperatures of all fruit within the range 0.0–2.0°C. In this study the temperature was monitored at a greater number of locations in the stow than in any previously published study, and sensors were placed to detect the highest and lowest temperatures. The results of other less rigorous studies, therefore, are not directly comparable.

Experimental Procedure

Two similar integral refrigerated containers, 6 m (20 ft) long and 2.6 m (8 ft 6 in) high, were selected, and were loaded with cartons of oranges, including some infested with Queensland fruit fly. One container was left in the open, at temperatures which varied around 15°C, to simulate preshipment treatment in Sydney, and the other was held in the test-room of the CSIRO Container Test Facility, at a constant temperature of 35°C, to simulate in-transit treatment while travelling through the tropics.

Containers

The containers were fitted with Email ESH 6B refrigeration units which delivered chilled air at ceiling level ('top delivery') at a nominal air circulation rate of 100 volumes/hour. These containers were fitted with wall and door battens, ensuring the flow of air over the walls and doors. The air circulation rate was checked before and after the trial using apparatus that collects the entire air stream (Irving and Shepherd 1982).

The containers' refrigeration units each had two temperature controllers, with independently adjusted setpoints; a conventional 'Partlow' electromechanical recorder-controller, and an RMC electronic controller. The Partlow controller recorded the temperature of the return air and controlled the return air temperature by switching the refrigeration compressor on and off as required. The RMC controller, which was activated only with setpoints above -4°C, allowed the compressor to run continuously, and regulated the temperature of the delivery air stream, using pulsed hot gas bypass.

Fruit

Early-season Valencia oranges, from six growers in the Mundubbera district of Queensland (150 km

inland, 300 km north of Brisbane) were harvested immediately before the trial, and were packed into vented C25 citrus cartons. These are fibreboard, two-piece cartons, comprising a lid with sides which fits over a base with sides, and have overall dimension of 450 (l) × 280 (w) × 260 mm (h). The cartons used for this trial were vented in all surfaces, giving total openings of 1.3% in the sides, 2.1% in the ends, and 5.5% in the base and lid. The fruit was not precooled, and was road-freighted to Sydney without refrigeration. A total of 644 cartons were stowed in each container, without dunnage (vertical wooden battens sometimes placed between tiers of cartons to ensure there are spaces for air to flow). The stow consisted of seven layers, with 11 full tiers and a turned tier located two tiers from the doors. (This stow, proposed by Japanese importers, left a headspace of 400 mm, sufficient to accommodate an additional layer to make a full stow of 736 cartons, still leaving a headspace of 140 mm.) The gaps between cartons of the turned tier were sealed at floor level.

Insects

A total of 1000 oranges infested with Queensland fruit fly (*Dacus tryoni*) were prepared at the Gosford Horticultural Postharvest Laboratory. Of these, 200 fruit were retained in the laboratory as controls, and the remainder were distributed amongst 10 cartons, five of which were stowed at random in each container. After the trial these fruit were returned to the Gosford laboratory, and the fruit were incubated for 3 weeks at 26°C over sand. The standard of survival was taken to be the formation of a normal puparium, judged as one which produced a live adult fly.

Temperature Measurement

Temperatures were monitored at 50 locations in each container, at 2-hour intervals, using thermocouples inserted into fruit placed at the centres of cartons located as shown in Fig. 2.

Operation

Immediately after the containers were loaded the refrigeration units were started with setpoints of 0.5°C. After 2 days it was apparent that the temperature spread in both containers was greater than 2°C. Accordingly the setpoints of the controllers were reduced in steps to give minimum fruit temperatures of 0.0°C.

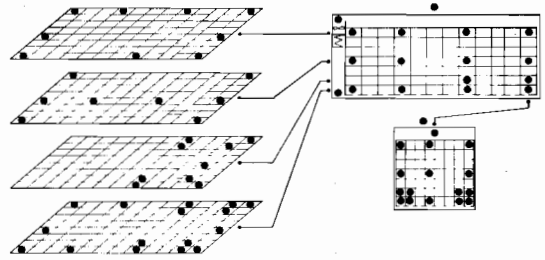


Fig. 2. Locations of the temperature sensors. A thermocouple was inserted into the centre of an orange which was placed at the centre of each marked carton. The sensors were monitored automatically every 2 hours throughout the trial.

The stowage pattern, too, was modified progressively to reduce the range of temperatures throughout the container. In their final stowage configurations, in the Outdoor container all vents permitting vertical air flow through the cartons were sealed. In addition to this, in the Testroom container gaps between cartons in the turned tier were sealed at the top surface of the stow as well as at floor level, and the door ends of the centre half of the floor channels were sealed. Details of the stow modifications are given below Table 3.

Results and Discussion

Performance of Containers

The containers operated as expected, except that the air circulation rates were less than that specified, and that they were unable to cool warm produce rapidly.

Although these containers have specified air circulation rates of 0.75 m³/sec, when measured before being loaded, air circulated through the Outdoor container at only 0.68 m³/sec, and through the Testroom container at only 0.53 m³/sec. A poorly fitting air duct inspection cover in the Testroom container allowed part of the airstream to bypass the loadspace; replacement of the adhesive-backed foam gasket increased the lower circulation rate to 0.67 m³/sec, but when rechecked at the conclusion of the trial the circulation rate had reverted to 0.53 m³/sec. It was assumed that both containers operated at 0.67 m³/sec (90% of specification) throughout the trial.

When cooling warm fruit, with the controllers adjusted to deliver air at +0.5°C, cooling was much slower than expected. This was traced to a faulty

Table 3. Summary of temperatures achieved in both containers, with various stows, after reaching steady-state conditions.

Container	Mean ambient temp (°C)	Stow	Set-point (°C)	Lowest temp (°C)	Highest temp (°C)	Temperature spread (°C)
Outdoor	12	A	0.5	0.7	2.9*	2.2
"	15	B	-0.3	0.0	1.6*	1.6
Testroom	34	A	0.5	0.7	3.2	2.5
"	34	B	0.5	0.8	2.7	1.9
"	35	C	-0.2	0.0	1.7	1.7
"	35	D	-0.2	0.1	1.9	1.8
"	35	E	-0.2	0.0	1.6	1.6

* cycling $\pm 0.4\text{ }^{\circ}\text{C}$ with daily change in ambient temperature.

Note: Stow A: fully vented cartons, gaps between cartons of the turned tier sealed at floor level.

Stow B: vents sealed in the upper surfaces of the top layer of cartons.

Stow C: all vent openings sealed in tops and bottoms of all cartons.

Stow D: spaces between cartons of the turned tier sealed at the top of the stow.

Stow E: the central half of the floor channels sealed at the door end of the container.

defrost system, which did not clear ice from the evaporator coils. When operating at constant temperature, and later when warming the stow, the Partlow on-off controller sometimes took over from the RMC controller, resulting in fluctuating temperatures. McLauchlan (1984) reported the same problem in an earlier study of similar containers. It would seem desirable for the on-off Partlow controller to be disabled when the RMC controller is active.

When operating at steady-state, the RMC controllers maintained constant delivery air temperatures, but showed calibration errors of $0.2\text{ }^{\circ}\text{C}$ (Outdoor container) and $0.4\text{ }^{\circ}\text{C}$ (Testroom container). Although very stable control of temperature is essential for cold-disinfestation, the accuracy of calibration of the controller is less important, because the temperature of the coolest fruit always must be monitored independently, to ensure it does not fall below the freezing point, and this temperature can be used to adjust the controller's setpoint. The temperature of the warmest fruit must also be known to ensure the specified quarantine treatment is applied.

Product Temperature

Two temperature parameters were of interest: the rate of cooling, and the steady-state temperature spread. Both depend on the temperature, the air circulation rate, and the uniformity of distribution of the circulating air. The air distribution depends on both the design of the container and its refrigeration unit, and also on the design of the carton, and on the way it is stowed. During the original cooling, the

stow consisted of vented cartons. The results given below refer to a nonvented stow, and were obtained at the conclusion of the disinfestation period, when the stow was warmed to 10°C , and then recooled to 0°C .

Temperature Spread

The temperature spread is the difference in temperature between the warmest and the coolest fruit in the container. If the controllers are adjusted to keep the coolest fruit just above the freezing point, the temperature spread determines the temperature of the warmest fruit. The effects of the various modifications made to the stow are shown in Table 3, which lists lowest temperatures measured at the coolest locations in each container with each stow, and the highest temperature measured at the warmest location in each.

These results show that the coolest fruit was always $0.2\text{--}0.3\text{ }^{\circ}\text{C}$ warmer than the delivery air temperature, and, for a given stowage pattern, the temperature spread was greater in the Testroom container than in the Outdoor container, showing the effect of the higher ambient temperature. With each of the stows most fruit were within a narrow temperature range, and in no case is it estimated that more than four cartons (i.e. 0.6% of the stow) were in the highest 0.5°C temperature range. While these few cartons could be ignored if only fruit quality were concerned, they are critically important in a quarantine treatment. Of the various modifications made, the only one to make a marked difference to the temperature spread was to seal the vent openings permitting vertical air flow through the cartons.

Since each pattern of stowage was symmetrical about the axis of the container, and the air delivery pattern is also nominally symmetrical, the fruit temperatures were also expected to be symmetrical. This was not the case, however, and temperatures of corresponding cartons on opposite sides of the container differed by as much as 0.5 °C. Furthermore, this could not be explained by an asymmetrical air supply system, because after the containers were restowed the higher temperature was sometimes found on the other side of the container.

Rate of Cooling

The response of a stow to a reduction in air temperature is commonly measured as the half-cooling time. The half-cooling times at various locations in the Testroom container, with the final stowage configuration, are given in Table 4 (these values of half-cooling time have been corrected for the faulty operation of the refrigeration unit).

Table 4. Measured half-cooling times of cartons at various locations in the container (Testroom container, final stow configuration).

Description	Location	$t_{1/2}$ * cooling
Fastest-cooling	Centre of lower edge near doors	27
-	Centre stow, 1/3 length from doors	51
Slowest-cooling	Centre stow, refrig. unit end	73
Eventual coolest	Near air delivery outlet	32
Eventual warmest	Lower outside corner near doors	28

* $t_{1/2}$ (hours) is the time taken for the temperature to change half-way from its initial to its final value.

Different parts of the stow cooled at greatly differing rates; the part which cooled fastest initially did not eventually become the coolest, because the initial rate of response at any part of the stow depends mainly on the local rate of air supply, whereas the eventual temperature depends also on the local rate of heat supply. Similarly, the part which cooled most slowly did not become the warmest.

Estimates of the time required to cool the last carton of a stow of nonvented cartons below 2.0°C, based on the measured cooling responses, but corrected for the poor performance of the temperature controller, are given in Table 5 for initial temperatures of 20°C (i.e. fruit not precooled), 10°C (i.e. fruit from a cool store), and 4°C (i.e. fruit pre-

Table 5. Estimated time required before the last carton has cooled to below 2.0°C from various initial conditions. (Final stow configuration, assuming delivery air temperature falls to 0.0°C immediately.)

Initial condition	Initial temperature (°C)	Cooling time (days)
Uncooled	20	6.7
Normal storage	10	6.5
Precooled	4	3.3

cooled to 2°C, and loaded in the open). Precooling would save 3.4 days, which might be important if the fruit was to be treated on land before export, but it is probably not important for in-transit treatment, because the container would usually be kept in the terminal, on power, for this period before export. The original fully vented cartons would allow the fruit to cool more rapidly, but these would not produce the required temperature uniformity.

Effectiveness Against Fruit Fly

From the 200 control fruit, 7234 normal pupae were recovered. Assuming the same ratio of insects to each of the infested fruit placed in the containers, a total of 28 936 insects in each container was exposed to the cold treatment. No survivors were detected, giving a mortality rate of not less than 99.997%.

Chilling Injury

Inspection of the fruit as it was being unloaded from the containers revealed some small brown pits characteristic of chilling injury. From each container 12 cartons of fruit were selected at random and stored at approximately 20°C. The remainder of the fruit was sold at the prevailing market price. After 3 weeks storage, to simulate marketing, the fruit were examined individually. A total of 45% of the fruit showed some injury, generally of a low level, but sufficient to affect its value on the Japanese market, but because there were no controls, it is not possible to identify this positively as chilling injury.

Conclusions and Recommendations

1. These containers, fitted with Email ESH 6B refrigeration units, are capable of keeping an entire stow of fruit within a temperature range of 2°C,

even at an ambient temperature of 35°C, and in this experiment maintained temperatures between 0 and 2°C for 17 days, which was sufficient to kill all Queensland fruit flies present.

2. The air circulation rate in both containers was below the specified value due to poorly fitting inspection covers. These covers should be re-designed.

3. If the minimum temperature of the fruit were set to -0.5°C, the maximum would be no more than 1.5°C, and cold-disinfestation treatment for Queensland fruit fly would be completed in 18 days under current USDA requirements. The treatment period could be shortened by lowering the temperature of the coolest fruit, but this would create a risk of freezing, should the temperature control system of the container's refrigeration unit be out of calibration.

4. Four temperature sensors are required per container, to provide evidence of adequate treatment for quarantine authorities: one to measure the minimum fruit temperature (to ensure no fruit is frozen), one to measure the temperature of the last fruit to cool to treatment temperature, and two to detect the maximum fruit temperature, because there are often differences between the temperatures of corresponding positions on opposite sides of the stow.

5. Stow temperatures depend to some extent on the vagaries of the particular stow. To cool fruit to the minimum temperature possible without freezing, it is advisable to measure the temperature of the coolest fruit directly, and to adjust the container's controller accordingly. This will compensate for calibration errors in the container's temperature control system. The temperature sensors mentioned above could be used for this purpose.

6. Cartons with vents in the upper and lower surfaces, permitting vertical air flow, are not suitable for cold-disinfestation because air short-circuits through the cartons, allowing the door-end of the stow to remain excessively warm. For the same

reason no dunnage should be used when stowing a container for cold-disinfestation. Preventing the air stream from contacting the fruit directly will also help preserve quality during the voyage by reducing moisture loss. However, to allow rapid pre-cooling before the fruit is loaded into the container, the cartons may still be vented in their sides and ends.

7. An undunnaged, nonvented stow cools relatively slowly, and precooling before loading into the container may be necessary to reach treatment temperature in an acceptable time, especially if disinfestation is to be carried out before shipment.

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Constraints on the Export of Fruit and Vegetables from Australia and Market Requirements Overseas

J.D. Baker *

AUSTRALIA is fortunate that the world's major population centres are in the northern hemisphere, giving us an excellent opportunity for out-of-season marketing. We also have a range of climates far greater than any of our southern hemisphere competitors (South Africa, Chile and New Zealand), enabling us to take advantage of a wider range of market niches.

Market indications for produce include:

Product	Market			
	Southeast Asia	Japan	Europe	North America New Zealand
Oranges	x	x	x	x
Lemons	x	x	x	x
Easy-peels			x	
Apples	x		x	x
Pears	x		x	x
Grapes	x	x	x	x
Kiwifruit		x	x	x
Cherries	x	x	x	x
Sugar Plums	x			
Stone Fruit	x		x	x
Avocados			x	x
Lychees	x		x	
Nashi fruit	x		x	
Mangoes	x		x	
Asparagus	x	x	x	x
Onions		x	x	
Melons		x		
Broccoli	x			
Chinese Cabbage	x			
Lettuce	x			
Ginger	x		x	

Southeast Asia

Fruit and vegetables worth approximately \$1000 million were imported into Hong Kong, Malaysia and Singapore in 1982-83, with Australia's share at \$80 million or 8%.

The breakdown between markets was:

	Total Imports	Imports from	Market Share
	A\$m	Australia A\$m	%
Hong Kong	575	20	3
Malaysia	150	29	19
Singapore	250	31	12

Hong Kong is the largest and fastest-growing market, yet it is the market where Australia has done very little. Based on the total import volume into Hong Kong and Australia's production base, it is realistic to believe that the following export volumes into Hong Kong could be achieved:

Apples	8000 t
Carrots	1000
Cabbage	4000
Grapes	2000
Lemons	1000
Melons	3000
Onions	3000
Oranges	35000
Pears	8000
Prunes	1000

* Secretary, Sydney Market Authority, P.O. Box 2, Flemington Markets, NSW 2129, Australia.

If these targets were achieved it would boost export revenue by at least A\$50 million.

Japan

Markets in Japan are already being serviced in a small way from Australia with products like onions, asparagus and oranges. Profitability in the onion business is based on being in the market every year to take advantage of shortfalls that can occur in Japanese domestic production.

The asparagus market has been well developed in recent years by producers and exporters from Victoria and New South Wales, and is a good example of how markets can be successfully developed and expanded.

The orange trade was opened to Australia 3 years ago but has been slow to develop. In 1987 it is likely to be around 1000 t. The main reasons for the slow development are the focus on processing by the industry and the lack of volume postharvest and packing facilities. Australia could realistically set a target of developing an export market of 50 000 t of oranges in the period June to November, in the northern hemisphere off-season.

Market access related to quarantine is an issue for most of Australia's other fruits and some vegetables. The Japanese have clearly indicated that the next products they are interested in obtaining from Australia include lemons, kiwifruit, cherries, grapes, melons, and apples.

Europe

Europe is a market that has been poorly serviced by Australia, and market share has been lost as other southern hemisphere countries have expanded their production. Countries like Chile would not have developed horticulturally to their present level if Australian producers and exporters had been more committed to the market over the past 10–15 years. Despite Australia's poor image in Europe there is still strong interest in obtaining produce from people who are committed to developing and servicing the trade.

There is a wide range of products that have potential in Europe, particularly pome and stone fruit, citrus, grapes and berry fruit.

North America

For development and servicing purposes, North America should be seen as at least three markets — east coast and west coast USA and Canada.

Canada represents a market bigger than Australia with a less varied range of products grown domestically. In the United States, Australia's export

volume is so small as to be almost unidentifiable. An indication of the market that is available can be gained from the fact that in 1985–86 Chile exported in excess of 21 million packages of fruit to the United States, yet this was insufficient to satisfy the off-season needs of the primary retail outlets. Main products were grapes, apples and stone fruit.

New Zealand

New Zealand represents a small but significant market for oranges, lemons, tomatoes and pears. It has the attraction of being close and easy to service. Limited opportunities for other products exist, because New Zealand does not have the range of climates for year-round production of vegetables or early season production of some fruits.

Constraints

Market Access

Major market access issues are Quarantine and Transport.

In the area of quarantine, the two markets restricted to Australian products are Japan and North America. Resolution of the quarantine issues needs to be based on discussions at both policy and technical levels.

The focus of transport in export horticulture has traditionally been on negotiating freight rates. However, the people negotiating freight rates have never had control of the product, and until this is so the exercise is pointless.

The two market access issues in transport are Service and Technology.

Two major markets currently restricted to Australian produce by the shipping service are Europe and Southeast Asia. With Europe all west-bound services terminate in the Mediterranean, and east-bound services to Northern Europe call at New Zealand. This effectively adds 10–20 days to the sailing times compared to 20 years ago. There needs to be coordination, both within and between industries, so that at key times of the year better services can be requested to northern Europe.

In the past 12 months the New South Wales Horticultural Export Development Council has concentrated its efforts on seeking a better service from the east coast to Hong Kong. This has now resulted in a one port load/one port discharge service between Sydney and Hong Kong, with the further result that

produce formerly shipped by air is now being sent by sea.

Shipping technology is another area for development. Industry knows that techniques like controlled and modified atmosphere containers are theoretically of value, but they have yet to be adopted adequately. In the area of air freight there are also materials such as one-use bubble insulation that could extend shelf life for highly perishable products like asparagus and cherries.

Product

Major constraints in this area are lack of supply, inconsistent supply and lack of organisation, and all three relate to each other.

The first two requirements of a market are consistent quality and consistent supplies, and until this is realised by the Australian export industry it will continue to be a price taker rather than a price setter on the international stage.

People

With few exceptions, there is a general lack of marketing skills, not just in horticulture but in agriculture in general. There is a major challenge in Australia to develop in people the necessary practical marketing skills that are required and recognised internationally. No educational institution in Australia is currently working in this area.

Finance

Exporting fruit, vegetables and flowers is an expensive business, as also is investment into the production of these products. Seasonal finance to cover the cost of export is generally not available, although steps are being taken to overcome this

problem. In the production area, large sums are needed to invest in farms of economic size, and with the waiting time until full production there has been little incentive for entrepreneurial investment in traditional horticultural products.

Overregulation

Regulations governing product standards for fresh fruits and vegetables have been developed largely by government, with some consultation of grower groups and the horticulture trade. In recent times emphasis has been given to the development of export regulations based on OECD standards.

Some of the results of this focus have been: (i) Development of minimum standards covering all markets (despite the fact that requirements vary from market to market); (ii) Emphasis being placed on quality control by government inspection rather than quality assurance by producers; (iii) Reliance on export regulations to define market specifications.

Materials-Handling

Australia can justly claim some recognition for its rationalisation of materials-handling on the domestic market, revolving around the Australian standard pallet and appropriate packages to suit. However, the Australian pallet is not used internationally, and industry has yet to come to grips with rationalisation of materials-handling procedures for export. The world is increasingly going towards a pallet of 1200 × 1000 mm or the shipping pallets similar to those used by New Zealand and South Africa.

Australia has to follow suit if we are to gain access to sizeable markets in the northern hemisphere.

An Exporter's Approach to Shipment of Fresh Produce from Australia

T. Pilavachi *

I AM one of the smallest exporters of fruits and vegetables operating from Flemington Markets, exporting mainly to Southeast Asia and Middle East countries. I believe that Australian produce has great prospects on world markets, but it is important for exporters to consider the following factors:

1. Successful exporters must be confident and persistent.
2. We must visit prospective clients regularly to get to know them and their requirements.
3. Reliability of supply is essential.
4. Freshness, size and visual appeal of the product are also very important.
5. Packaging must be attractive as well as safe, and a logo with a strong local motif (such as a kangaroo inside a map of Australia) is an advantage.
6. Free samples can help to capture export business (and the cost is refundable).
7. You should occasionally accompany your shipment overseas to see in what condition the goods arrive at the destination.
8. Quotations for fruits and vegetables should be telexed to prospective importers regularly (at least once a week).
9. Ask your importers if they are satisfied with your operations.

During autumn and winter months exporters may depend entirely on Queensland produce, but some of the packaging used by these growers is unsatisfactory. The produce requires repacking, which is labour-intensive and an additional expense, and this

subject requires further attention. Currently, there are over 100 different packages used in the Australian horticultural industry, and some rationalisation is required.

Exporters must deliver the appropriate product to the importer in the right quantity at the right time and in the best possible condition. It is also necessary to undertake promotional campaigns, which are vital elements in any marketing strategy.

Export Strategies

The United States is Australia's main competitor in Southeast Asia. American exporters have recognised for some time the importance of reducing distribution costs in supplying large volumes of high quality, competitively priced produce to a distant market on a regular basis. An example is the 'Sunkist' effort, which has established itself in the minds of consumers as synonymous with premium quality, and the organisation has successfully set out and maintained the quality and packaging standards by which all other citrus fruits are judged in Asia.

Sunkist in fact consists of some 12 individual packing concerns in California, but by carefully coordinating activity the organisation is able to regulate acid levels, packaging, marketing and promotion, to ensure that citrus of varying sweetness is directed and sold according to the differing consumer preferences of different countries. For example, low acid fruit is preferred in Asia, while high acid fruit is sent to Western export markets.

I have not found the Sunkist taste particularly

* Terry's Export Produce Pty Ltd, Market Plaza, Flemington, NSW 2129, Australia.

good, and when I organised tastings of Australian oranges, which I consider to be better, they were a great success. However, it will require a carefully

planned and coordinated operation, such as that of Sunkist, for Australia to make effective, long-term penetration of these markets.

Transport of Perishables by Road

T.O.D. Hughes *

THE carrier of perishables by road transport has to recognise two principal functions: (1) the transport function of moving products from one point to another in a given time; and (2) the processing function which requires the carrier to maintain the Cold Chain preservation process during the journey.

The Cold Chain is a quality preservation process, operating through from harvest to consumption and involving biochemical physical and microbiological aspects.

Different Cold Chain operating specifications are required for different perishable food products. This paper will principally consider the application of the Cold Chain to fruits and vegetables.

Transport is a significant proportion of the cost of the product's selling price. Each fruit and vegetable has its own temperature characteristics, and these vary under different conditions. It is necessary for those engaging road transport to fully brief the carrier of the relevant Cold Chain specifications, so that produce arrives in optimum condition.

In trades of limited cargo, it may be necessary to transport various products with different Cold Chain specifications. Also, some products may taint the taste and smell of other products in the load. There is considerable information available as to desirable maintenance temperatures and the compatibility of different products.

Road haulage of perishables requires understanding of heat of respiration of produce. After harvest the produce, under normal conditions, continues to 'breathe,' giving off heat and generating carbon dioxide. The heat given off is known as the heat of

respiration, and varies considerably from product to product.

When the produce has been cooled to a specified transport or storage temperature, respiration and hence heat generation is no longer significant. Reduction in respiration can also be achieved by modifying the composition of the atmosphere surrounding the produce.

If the respiration is allowed to continue, steps have to be taken to ventilate away the carbon dioxide, as a high concentration can suffocate the produce.

The first link in the Cold Chain for fruit and vegetables is precooling, whereby the product temperature is reduced from field heat to the desired temperature. Ideally, field heat should be removed rapidly and evenly, and the product should not regain sufficient temperature to cause significant respiration. The most effective precooling is carried out in properly designed terminal facilities, but en route precooling is also practiced. Good terminal precooling can present opportunities for much cheaper forms of transport under appropriate conditions.

To carry out this process responsibility fully, the carrier needs the following information:

Product Requirements

The carrier should have access to general data on all products, such as temperature, relative humidity, and controlled atmosphere ventilation requirements, critical minimum temperature (for damage), heat of respiration generated, susceptibility to physical damage and preferred stowage arrangements, and which products are incompatible in mixed loads.

* Transport Consultant, Queensbury Pty Ltd, 5 Shinfield Avenue, St. Ives, NSW 2075, Australia.

Specific Details of Each Cargo

Such information includes nature and quality of products to be carried, extent of precooling if any, nature of packaging and any stowage patterns required, use of bulk bins or pallets, and size of load. The carrier should also know the market expectation of delivered quality, since there is unnecessary expense in supplying an unsophisticated market requirement by way of sophisticated refrigerated transport.

Bulk bins can help by keeping incompatible cargoes separate, and permitting carriage of mixed loads with different temperature or other requirements. There is also less handling involved in loading and unloading.

Route Conditions

Important factors are road quality (load cushioning may be required), route limitations on vehicle size, likely ambient temperatures and weather conditions, distance and expected trip time, terminal facilities at either end and any requirement for enroute facilities.

Economic Factors

The most profitable results require well-organised loads which are full in both directions. Where this is not possible, operational modifications may need to be considered. For the refrigerated carrier, the weight and the reduced internal cargo space measurements make it difficult to carry dry cargo

competitively. Single-purpose vehicles employed in a seasonal trade where there is no alternative application for the vehicles face uneconomic cost structures. Seasonal trades require an examination of the possible short-term modification of dry cargo vehicles.

En-Route Process Equipment

Important factors to be considered are:

(a) Quality of insulation, which will determine degree of refrigeration required. Insulation may be reflective against radiation, e.g. aluminium foil (best as two separate layers 25 mm apart), or by insulating layers of foam or gas against conduction. Air leakage must be minimal.

(b) Body construction, in relation to sealability, and requirements for hygiene, loading convenience, ventilation, durability, weight and cost of maintenance.

(c) Refrigeration techniques, which may be non-mechanical (ice, dry ice, eutectic plates, etc.) or mechanical (by compressor, evaporator, condenser or fans, driven either by the prime mover or by a separate combustion engine). Each has particular features, and the carrier must judge which is best suited to the load requirements.

(d) Airflow, which is determined by body construction but can be affected by blockage of inlets and by resistance or short-circuiting caused by the pattern of stowage. The carrier must be fully aware of the load requirements and how such shortcomings can be avoided.

Shipment of Fresh Produce by Air

Roger Parkes *

SOME years ago air cargo was the poor cousin to passenger traffic within Qantas, but not today. The cargo business might still be smaller than the passenger business, but it commands equal respect within the corporate headquarters of Qantas, and it plays a significant role in Australia's export drive. About 130 times each week Qantas jets fly out from Australia to the rest of the world, to 30 ports in 24 countries. England and Europe, Asia, North America, Africa and countries in the South Pacific (including Papua New Guinea) are all on the Qantas network. Every week Qantas aircraft carry overseas about 1000 t of Australian exports, worth more than A\$20 million.

Bulk commodities such as ore, coal, grain and wool are only suited to surface transport (normally by foreign-flagged ships, at a cost to Australia's balance of payments). It is the more valuable products that warrant airfreight, which accounts for 1% of weight but 8% of total value of Australia's exports.

Surplus air cargo space is generally available, at highly competitive rates. For example, a typical airfreight rate from the US West Coast to Australia is A\$6/kg, whereas the rate available to Australian

exporters sending primary produce in the other direction is about A\$1.50/kg, one of the cheapest air cargo rates in the world.

Fresh fruit and vegetables comprise Australia's main export items by air. About 70% and on some routes as much as 90% of Qantas's total cargo flown from Australia comprises foodstuffs. Perishable cargo does present difficulties not found with manufactured products, however. It has to be kept at low temperatures, and so requires special packing. It needs cool rooms at cargo terminals, for delays on a hot tarmac could result in a condemned consignment. It is highly seasonal, and so demands an inordinate amount of capacity for just a few short weeks of the year. It is subject to health inspections and special documentation. It is subject to the vagaries of the weather and the unpredictability of production, and so predictions of capacity demand are hazardous at best.

Despite these requirements, Qantas decided a few years ago to establish a special cargo division, and demonstrated its faith in the future of perishable air cargo by massive investment in airport terminal and aircraft hold facilities, complex cargo tracking facilities, and a cargo staff of 600 people. The facilities are there — it is now up to growers to produce the goods that merit them.

* Director of Cargo, Qantas Airways Limited, GPO Box 489, Sydney, NSW 2001, Australia.

Selection of the Right Packaging: Engineering Aspects of Package Design

L.B. James *

THE aims of packaging for fresh produce are:

- (a) To protect produce from physical, physiological and pathological damage;
- (b) To assemble produce in marketable quantities and present it to the market in a form and condition that entices buyers; and
- (c) To facilitate handling through the various distribution systems involved.

One of the first steps in a package design project is to investigate the extent to which distribution systems and methods can be modified to reduce the hazards to produce, and the possible use of techniques such as forced cooling, gassing, etc.

Fundamental to the actual produce packaging is protection. Engineering principles first need to be applied to package design in deciding shapes, sizes, ventilation and cooling of produce in boxes. Next comes choice of styles to facilitate all aspects of handling. It is only after these steps have been considered that the structural design aspects of package development come into play.

The following are the basic design and engineering considerations:

- (1) Ability of the package to withstand rough handling, some level of which is unavoidable in the distribution system. This is referred to as containment strength;
- (2) Ability of the package to support the stacking loads imposed in transport and storage operations; and
- (3) Ability of the package to resist distortion, such as bottom sag and container bulge.

Containment strength may be provided through choice of style, package components and special additions such as tension tapes/strings, etc., but above all by overhauling the distribution system and handling methods and thus minimising the hazards which cause the need for extra strength. Fork lift handling and containerisation have been major advances in this regard.

It is in considerations 2 and 3, however, that the greatest advances have been made in recent times. Properly engineered packages can provide improved performance at lower cost, through optimum choice of components and their disposition within the structure of the box.

Traditionally Australia has manufactured waste-paper based linerboards, which have good stacking properties but suffer by comparison with virgin fibre grades. Containability is less because tear strength is lower, and ability to cope with high humidity conditions is also less.

In June 1985, APM introduced a new range of Kraft Liner Boards which have since taken over the bulk of the local market. They contain a blend of long fibre for adequate containability and creasing quality, and short eucalypt fibre for high stacking strength, and are also significantly lower in price than the superseded grades.

Complementary to this was the introduction of a virgin fibre corrugating medium — Supaflute 180, to join the range of mediums from low-crush 120 gsm (for use in wraparound situations where no stacking strength is required, but conformability in high-speed packaging machinery is vital), through a general-purpose 117 gsm product, to high performance 155 gsm and ultimately, the Supaflute 180.

Performance of boxes, with regard to stackability

* Product Manager — Container Materials, Australian Paper Manufacturers, 685 Bourke Road, Camberwell, Vic 3124, Australia.

and bulge resistance, is largely controlled by the inside liner and the medium of the corrugated board selected. Thus it is still valid to use waste-based White Liners on the outside for enhanced graphics and market appeal without loss of box performance, and this is one of the fastest growing sections of the box market.

High stress conditions such as high or cycling humidities and long-term storage of heavy boxes in stacks, can be allowed for by extra wet-strengthening, or treatment with wax or resin.

Even well-designed boxes encounter problems from overfilling, and from poor pallet stacking and alignment, and it is necessary for the Packaging

Engineer to allow safety factors of 4, 5 or even 10 times the actual stacking requirements of a box, to cope with the real world situation.

In summary, good packaging will: protect the product and reduce waste and damage; reduce process and handling time in plant and equipment; facilitate handling and automatic processing; facilitate inventory control and order-picking; allow full utilisation of available warehouse space; ease normal handling and inspection procedures; contribute to conservation and recycling of materials; promote product market image; meet statutory regulations; facilitate price-marking, shelf-loading and similar operations, and enhance user convenience.

Transfresh System of Atmosphere Control

Glen Adams *

THE following specifications, taken from one particular contract, indicate the capabilities and construction of the Transfresh atmosphere control system:

(1) Design Parameters

(a) Room dimensions:

Width: 10 255–12 400 mm

Depth: 11 200 mm

Height: 3000 mm

(b) Insulation:

150 mm walls and ceiling; no floor insulation

(c) Product load:

Nine pallets of various produce to be pressure-cooled in 6–8 hours from 32 to 1°C.

Average specific heat .92 BTU/lb.

(d) Ambient temperature:

40°C dry bulb, 29°C wet bulb

(e) Room temperatures:

0–15°C maintaining average humidity levels of 95–96%

(2) Refrigeration equipment

Each room has the following installed:

(a) Air handler:

Thermfresh model HH18F high humidity air handler, constructed with a 20 mm marine ply casing which is fibreglassed inside and out after fabrication.

The evaporator is a multi-circuited copper tube bare pipe evaporator, electro-tinned after fabrication. Two backward curved fans are mounted at each end of the cabinet, and have a total air flow of 18 000 CFM.

The heart of the system is the fill, which has been designed to obtain maximum heat transfer with the air and water which pass in a counter-flow direction through the fill (patent pending).

Water is recirculated within the air handler by means of a high volume, close-coupled pump.

Excess water in the air that has passed through the air handler is totally removed by means of eliminators mounted on top of the cabinet.

Height of air handler: 2480 mm.

(b) Condensing unit:

Thermpak model NT15–2 × 15 package condensing unit, factory-assembled, processed and precharged with refrigerant. The unit is prewired so that on delivery to the site it only requires the suction and liquid lines to be installed, and interconnecting wiring to be completed.

(c) Construction:

Channel steel base with square tube steel frame, all galvanised after construction. The frame is then weatherproofed with a colorbond steel case, with access doors for service.

(d) Compressors:

Terry model 1000B multi-cylinder reciprocating compressors, each with splash feed lubrication, and belt-driven by 15 HP, 3φ electric motors. The compressors are 100% unloaded on start, and are fitted with HP and LP controls.

(e) Condensers:

C.T.S. model RC 160 air-cooled condensers, each constructed with a copper tube aluminium fin core and aluminium outer casing.

(f) Controls and fittings:

Liquid line driers

Liquid line moisture indicators

Liquid line solenoid valves

Discharge mufflers

Thermostatic expansion valves

Ice Bank thermostat

* Co-ordinated Thermal Systems Pty Ltd, Refrigeration Engineers and Designers, 42 Henderson Road, Clayton VIC 3168, Australia.

(g) Electrical panel:

Comprising HRC fuses, motor starters and overloads, delay timers, phase failure relay, hour run meters, neon indicator lights for faults, and mains isolating switch. Panel mounted switches are provided so that each system can be shut down on a pump-down cycle when not required.

(h) System capacity:

178 908 BTU/hour (52.3 kW) with an air-off temperature of 0.5°C.

(3) Remote control panel

Installed in a convenient position within the complex, and incorporating the following:

(a) Kent model P250 12-point recorder (250 mm chart)

(b) Probes for recorder

(c) Room thermostats — Shimaden electronic resistance bulb

(d) System isolating switches

The panel is constructed with a stainless steel front, and a steel main frame powder-coated after fabrication.

(4) Buffer strips and blinds

Buffer strips fitted around pressure cooling openings, manufactured with a foam rubber insert covered with heavy duty reinforced PVC sheeting.

Pressure cooling blinds also manufactured from reinforced PVC sheeting with timber battens at 1-m intervals.

Trials have been conducted with this system on apples shipped to the United Kingdom, blueberries, nectarines and pears shipped to the United States, and honeydew melons shipped to Hong Kong; also avocados shipped from Mexico. Comparative trials with honeydew melons indicated that with refrigeration the fruit arrived in good condition and had the standard 7 days shelf life; with modified atmospheres the fruit were also in good condition and had an extra 14 days of shelf life, and with controlled atmospheres the fruit were again in good condition and had an additional 21 days of shelf life.

The controlled atmosphere system costs A\$1150 extra, the modified atmosphere A\$750 extra; in both cases this is on top of the cost of refrigeration. There is no cost of gases to be added to the shipment; the gases are generated by the product, and the system merely controls the ratios and levels of the gases. The controller is accurate to $\pm 0.5\%$. A teledyne sensor is used for oxygen measurement. The maximum acceptable leakage of the system is 7 min half decay time.

Participants

The following list includes many of the persons who attended the workshop. However, because of the diversity of groups interested in the subject, the meeting was widely advertised and open to anyone who wished to attend, and not all names were recorded.

- G. Adams**, Co-ordinated Thermal Systems Pty Ltd., Refrigeration Engineers and Designers, 42 Henderson Road, Clayton, VIC 3168.
- J. Aiken**, Principal Consultant, Compass Consulting Services, 5/20 Cliff Street, Milsons Point, NSW 2061.
- Garth Atkinson**, Department of Primary Industry, PO Box 417, Konedobu, Papua New Guinea (current address: ACIAR, GPO Box 1571, Canberra, ACT 2601).
- J.D. Baker**, Secretary, Sydney Market Authority, PO Box 2, Flemington Markets, NSW 2129.
- H.J. Banks**, CSIRO Division of Entomology, GPO Box 1700, Canberra, ACT 2601.
- B. Beattie**, New South Wales Department of Agriculture, PO Box K220, Haymarket, NSW 2000.
- G.R. Chaplin**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- S. Cole**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- M. English**, Avocado Growers Association of New South Wales, Main Arm, Mullumbimby, NSW 2482.
- P. Ferrar**, ACIAR, GPO Box 1571, Canberra, ACT 2601.
- J. Forsyth**, New South Wales Department of Agriculture, PO Box K220, Haymarket, NSW 2000.
- D. Graham**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- G. Hicks**, New South Wales Department of Agriculture, PO Box K220, Haymarket, NSW 2000.
- T.O.D. Hughes**, Transport Consultant, Queensbury Pty. Ltd., 5 Shinfield Avenue, St. Ives, NSW 2075.
- A.R. Irving**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- L.B. James**, Product Manager-Container Materials, Australian Paper Manufacturers, 685 Bourke Road, Camberwell, VIC 3124.
- A.R. Johnson**, Officer-in-Charge, CSIRO Food Research Laboratory, PO Box 52, North Ryde, NSW 2113.
- R.A. Jordan**, Queensland Department of Primary Industries, Sandy Trout Food Preservation Laboratory, Hamilton, QLD 4007.
- E.E. Kavanagh**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- T. Limbert**, Banana Growers' Federation Co-operative Limited, PO Box 31, Murwillumbah, NSW 2484.

- B. McGlasson**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- S. Morris**, New South Wales Department of Agriculture, Gosford Horticultural Postharvest Laboratory, PO Box 355, Gosford, NSW 2250.
- R. Parkes**, Director of Cargo, Qantas Airways Limited, GPO Box 489, Sydney, NSW 2001.
- B.C. Peacock**, Queensland Department of Primary Industries, Sandy Trout Food Preservation Laboratory, Hamilton, QLD 4007.
- I.D. Pegg**, Victorian Department of Agriculture and Rural Affairs, Knoxfield Horticultural Research Institute, PO Box 174, Ferntree Gully, VIC 3156.
- G.J. Persley**, Research Program Coordinator (Crop Sciences), ACIAR, GPO Box 1571, Canberra, ACT 2601.
- T. Pilavachi**, Terry's Export Produce Pty. Ltd., Market Plaza, Flemington, NSW 2129.
- S. Satyan**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- K.J. Scott**, New South Wales Department of Agriculture, C/- CSIRO Food Research Laboratory, PO Box 52, North Ryde, NSW 2113.
- A.K. Sharp**, CSIRO Division of Food Research, PO Box 52, North Ryde, NSW 2113.
- L. Shepherd**, Cargo Standards Manager, Qantas Airways Limited, GPO Box 489, Sydney, NSW 2001.
- W.J. Singleton**, Banana Growers' Federation Co-operative Limited, PO Box 31, Murwillumbah, NSW 2484.
- S. Spraggon**, CSIRO Food Research Laboratory, PO Box 52, North Ryde, NSW 2113.
- B.L. Tugwell**, Senior Research Officer, Postharvest Horticulture, South Australian Department of Agriculture, Northfield Research Laboratories, Box 1671, Adelaide, SA 5001.
- N.L. Wade**, New South Wales Department of Agriculture, C/- CSIRO Food Research Laboratory, PO Box 52, North Ryde, NSW 2113.
- C. Warisaiho**, Department of Primary Industry, PO Box 417, Konedobu, Papua New Guinea.
- B.L. Wild**, Senior Research Horticulturist, Gosford Horticultural Postharvest Laboratory, PO Box 355, Gosford, NSW 2250.

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