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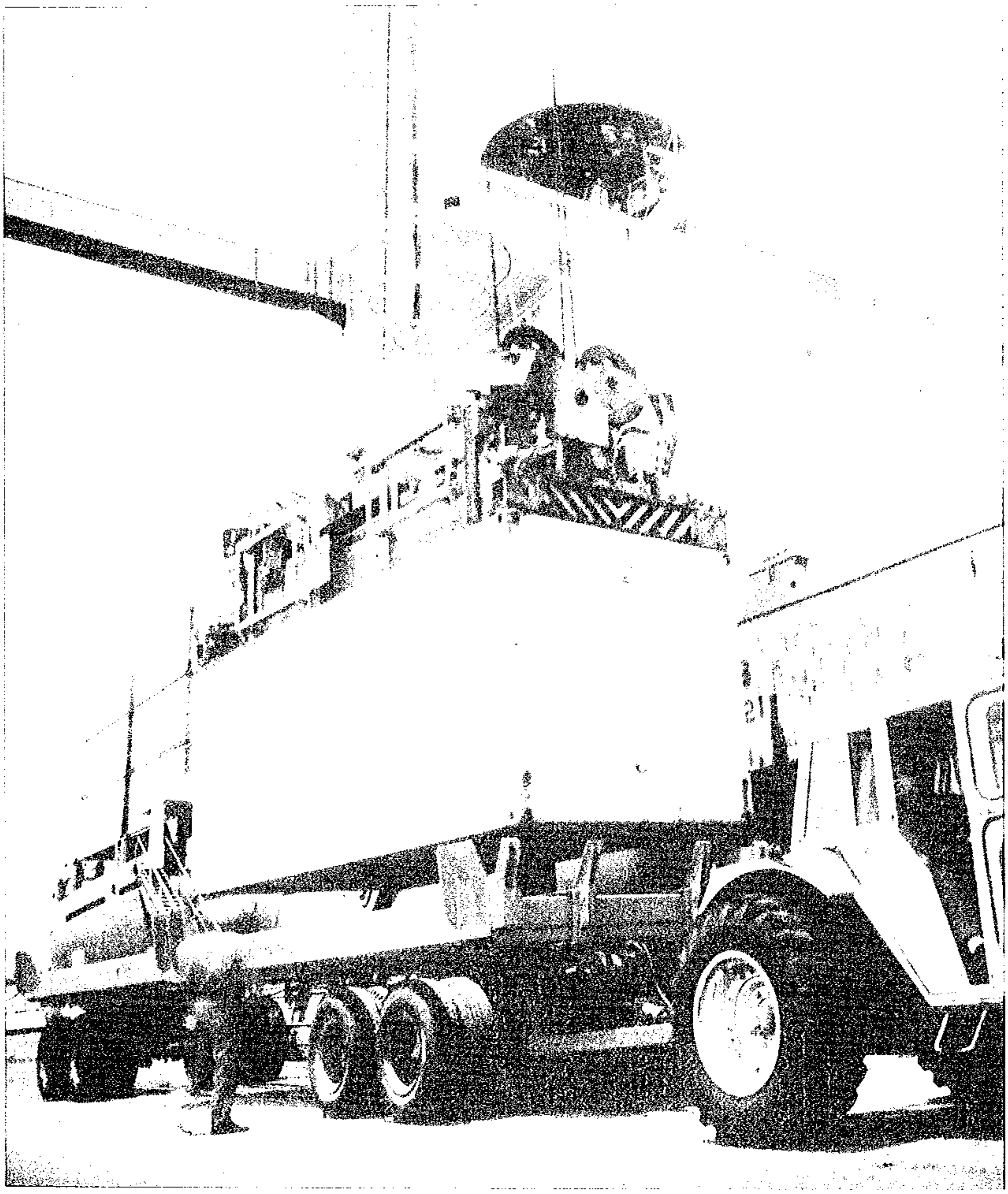

Refrigerated shipping containers: Understanding their operation and using them effectively for the carriage of horticultural produce

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Introduction

At present the Federal and State Governments of Australia are promoting exports of traditional horticultural produce, as well as less traditional produce: large quantities of many 'new' crops have been planted and as production increases, export markets will be needed to take the excess produce. To ensure the export of high quality produce, care must be taken with all the links in the chain from the field to the consumer: proper handling procedures during harvesting, sorting and packing, together with good temperature management, are essential. The last link in this chain is transport. While some of the highly perishable 'new' crops require air transport, high volumes of perishable produce must be carried in refrigerated shipping containers. If this export promotion is successful, many more people will come into contact with these containers.

There is considerable confusion, even among some who have used refrigerated containers for a long time, about certain aspects of their operation. This article is an attempt to clarify, particularly for those new to containers, some of the 'jargon' (summarized in Table 1) used in talking about containers, to describe the different modes of operation of container refrigeration systems and to discuss the use of containers to obtain good rather than poor quality produce on arrival at the destination (i.e. at outturn).

Basic description of a container

A refrigerated container essentially consists of three parts: 1) an insulated box, 2) a refrigeration system, and 3) an air circulation and distribution system.

The insulated box has external dimensions of 6.06 m (or 12.12 m) long by 2.44 m wide by 2.44 m high (Fig. 1). The height of older boxes is 2.44 m, but most new ones are 2.59 m (or even 2.74 m) high and are sometimes referred to as hi-cube. For simplicity, values mentioned in this discussion refer to 6.06 m long containers. When containers are new, heat can leak through their insulation at a rate of 20 to 30 W/C (watts per degree temperature difference), depending on the construction.[1] Thus, if there is a difference between the inside and outside temperatures of 30℃, the heat leak rate is between 600 and 900 W.
The insulation deteriorates at a rate of about 5% per year.

Attached to, or part of, this container is the refrigeration unit which acts as a source of cold (or warm) air; the refrigeration unit includes a refrigeration (and heating) system (compressor, evaporator and condenser with associated valves and controls) to cool (or heat) the air, a fan to circulate the air through the container, a temperature controller and a temperature recorder. While the refrigeration system has sufficient capacity to cool cargo, the air flow system is not designed to allow cooling to be done quickly. Thus, containers should not be regarded as devices to cool cargo but as devices *to maintain cargo temperature.*

The floor of the container is made of T-bar channel sections (Fig. 1) to allow movement of air beneath the cargo. Most earlier containers have some form of wall battens to keep the cargo from being in direct contact with the walls and to allow air to flow over the walls to remove the heat leaking into the container. However, to cut down maintenance costs, many containers are being built now with smooth walls. There is some evidence to suggest that less air flows over the walls of

[1] In this discussion C is used to mean a difference in temperature while ℃ indicates a given temperature.

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TABLE 1

Summary of terms used to describe containers

Bottom delivery	Air enters the bottom of the cargo space into the T-bar floor and flows upwards.
Capacity control	When carrying chilled produce, the refrigerating power or capacity of the unit is reduced so that it can run continuously and give better temperature control.
Carriage temperature	The mean temperature at which the produce is actually shipped. The desired produce temperature during transport may be different to the carriage temperature.
Ceiling gap	The gap between the top layer of cartons and the ceiling of the container to allow free flow of the circulating air. Export regulations require a minimum gap of 50 mm.
Cellular ship	A ship built with cell guides specifically to carry porthole containers. The ship is divided into cells and all containers in one cell are carried at the same temperature. Integral containers may be carried on deck.
Cold disinfestation	Usually refers to the killing of fruit fly by holding all fruit temperatures below a specified temperature for a specified number of days e.g. below 1.1°C for 18 days for Queensland fruit fly.
Condenser	That part of the refrigeration unit where the hot refrigerant gas loses heat and condenses to a liquid.
Cool-down	The initial period after switching on the refrigeration unit on a loaded container while the produce is cooled to the carriage temperature.
Clip-on	Portable refrigeration unit that fits onto the end of a porthole container.
Cross-row	See turned tier
Delivery air control	The refrigeration unit is controlled from a sensor located in the air stream being delivered into the cargo space.
Dunnage	Wooden battens, 10 mm thick, placed vertically between cartons to allow air movement.
Evaporator	That part of the refrigeration unit where the refrigerent liquid absorbs heat from the surroundings and turns into the gas phase.
Head gap	See ceiling gap
Hi-cube	Containers that are 2.59 m high, giving a higher cubic capacity
Hot-gas bypass	A method of capacity reduction of the refrigeration unit where hot refrigerent gas is directed into the evaporator.
Insulated container	See porthole container.
Integral container	Container with a refrigeration unit built into the end.
On/off	Simple method of controlling temperature by turning the refrigeration compressor unit on and off.
'Partlow'	The most common make of temperature recorder/controller that is fitted to containers. The Partlow has a 200 mm dia. circular chart.
Plenum	A space from which, or into which, air flows. The space allows the air to be distributed more uniformly.
Porthole container	A container with two holes (ports) in the end wall for attaching an external supply of refrigerated air.
Pre-trip	Complete check by serviceman of the refrigeration system before a container is sent out for loading.
Return air control	The refrigeration unit is controlled from a sensor located in the air stream returning to the evaporator from the cargo space.
'Ryan'	A make of portable temperature recorder that is placed in containers by some exporters to give an independent record of temperature. Other makes such as 'Cox' and 'Autolog' are used also.
Short-circuiting	The circulating air in the container flows through inadvertent gaps in the stow, resulting in poor flow in other sections.
Short-cycling	The refrigeration unit switches on and off too frequently.

TABLE 1 — Continued

Suction throttling	Method of capacity reduction of the refrigeration unit where a valve restricts the flow of refrigerant gas to the compressor.
Top delivery	The air enters the top of the cargo space and flows downwards.
Tower unit	A bank of refrigeration units, usually at or near a wharf area, to which porthole containers can be attached while waiting transfer to a ship.
Turned tier	A vertical column of cartons that are stowed with the long dimension of the cartons being across the container instead of lengthways down the container.

smooth-walled containers than over those in containers with wall battens, resulting in higher temperatures of cartons against the walls.

Types of containers

There are two types of refrigerated containers, the porthole and the *integral container* (the correct name for a porthole container is an insulated container but porthole is common usage). The porthole container is an insulated box with two holes or ports in the end wall (Fig. 2). Refrigerated air is delivered to the bottom porthole and flows into a plenum which distributes the air into the T-bar floor channels. The air flows into the cargo space and leaves through a slot, 50 to 100 mm deep, which runs the full width of the container in the top of the plenum wall. The air leaves the plenum through the top porthole. On land, while awaiting loading onto a ship, a portable electric — clip-on — refrigeration unit can be fitted to the end of the container or, alternatively, in some ports the container can be attached to a refrigeration tower unit. On board a cellular container ship, porthole containers are stowed below deck and are supplied with air from a central refrigeration plant which the ship's engineers can supervise easily. All containers in each cell of the ship receive refrigerated air at a common temperature. Containers in other cells may receive air at different temperatures. Sometimes porthole container are shipped on deck with a clip-on unit attached and then they are essentially the same in operation as an integral container.

An integral *container has its own* refrigeration unit built into the end of the container (Fig. 3). Each unit has an evaporator fan(s) to circulate the air over the refrigeration evaporator coils and through the container. From a plenum the air may either enter the cargo space via the T-bar floor (bottom delivery), as in porthole containers, and return *to the refrigeration* unit through a slot in the top of the end wall, or alternatively, the air may enter the cargo space through the slot at the top (top delivery) and return via the T-bar floor. The direction of air flow determines where the hottest and coldest produce will be located in the container, but otherwise there is little difference between the two systems. Each unit has its own controller and recorder and so there are many dispersed control points on board ship instead of one central plant.

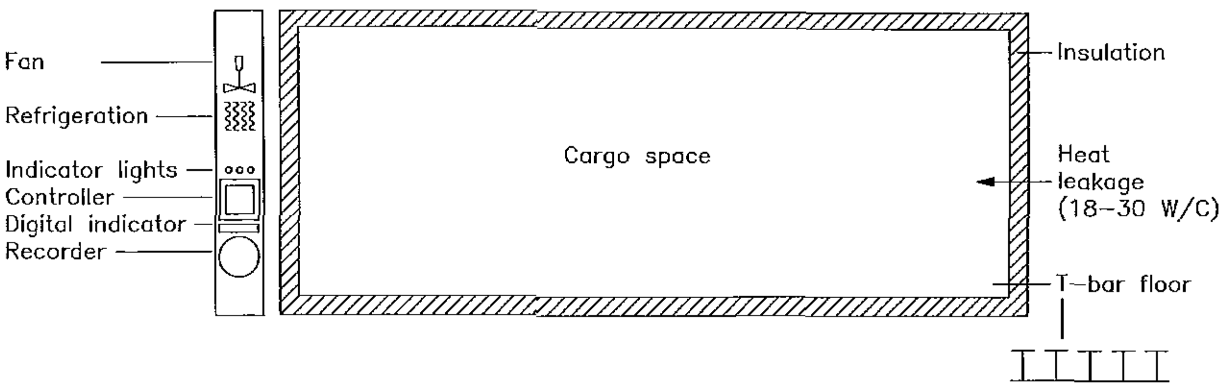


Fig. 1. Main component parts of a refrigerated container. (External length: 6.06 or 12.12 m, width: 2.44 m height: 2.44 or 2.59 m)

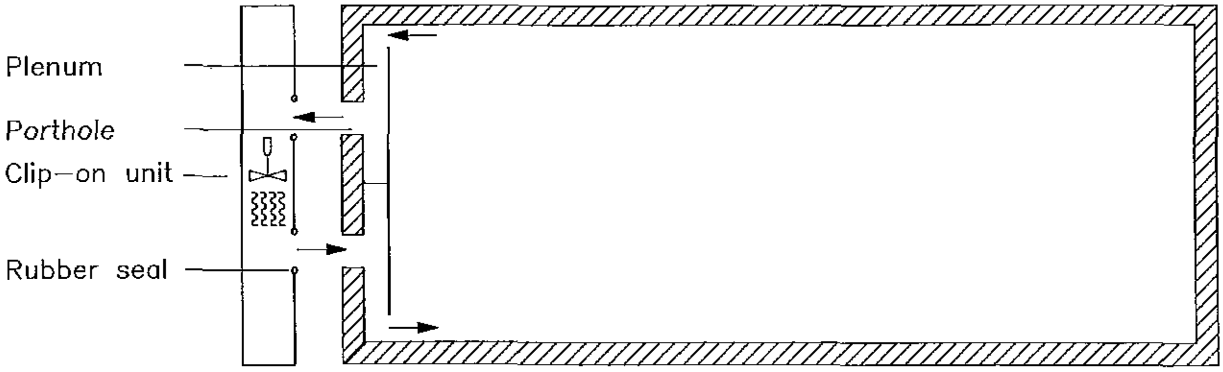


Fig. 2. **Porthole container showing ports, plenum and clip-on unit. The air flow is from bottom to top. (Internal length: 5.64 to 5.69 m)**

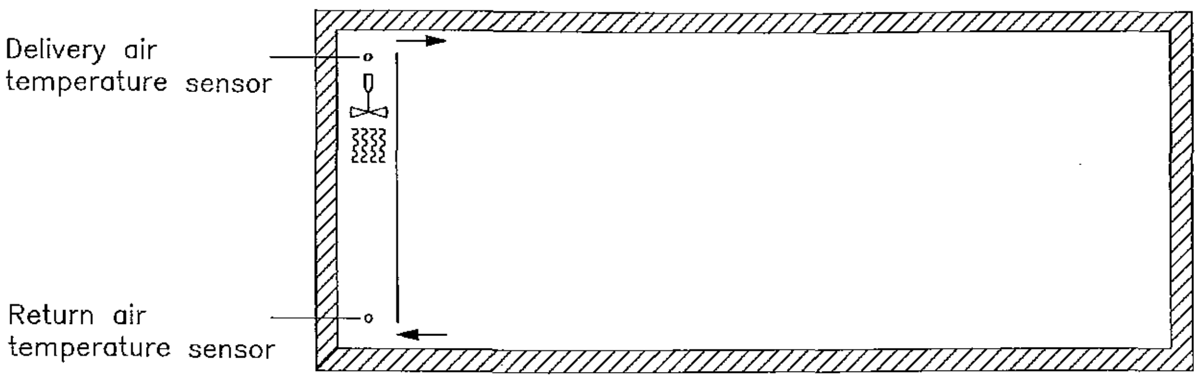


Fig.3. **Integral container with refrigeration unit built into the container and showing the positions of the temperature sensors for the controller/recorder. The air flow may be top to bottom (as shown) or bottom to top. (Internal length: 5.31 to 5.45 m)**

External environment during shipment

Porthole containers carry Australian exports to Europe and America only, while integral containers are used on all trade routes. On most cellular ships, the holds in which porthole containers are carried operate between 5° and 10°C and can be cooled further, to 2°C, if the produce in the container is undergoing cold disinfestation. In contrast, integral containers are placed either in unrefrigerated cellular or vehicle holds or on deck where the ambient temperatures can reach 30° to 40°C while the ship passes through the tropics; the condensers on the refrigeration units on the containers in the cellular holds may be water-cooled to allow more efficient operation.

The high temperature ambient environment increases drastically the amount of heat that leaks through the insulation into the containers. Using a value of heat leakage of 26 W/C and assuming an internal temperature of 0°C, the heat leakage into porthole containers can range from 52 to 260 W but for integral containers can reach 780 to 1040 W.

For comparison, the heat of respiration generated by a container load of pears at 0°C is 150 W or oranges at 10°C is 350 W. The relative proportions of heat generated by the produce and heat leaking through the container walls determine how the circulating air should be distributed. Thus, because of the different environments in which they are shipped, the two types of containers ideally require different air distribution patterns, but this is not practical.

Air temperature rise and air-flow rate

As the refrigerated air circulates in the cargo space of the container, it absorbs the heat leaking through the walls and being generated by the produce. Consequently, the temperature of the air leaving the cargo space is higher than that of the air entering the cargo space; the amount the air temperature rises depends on the total air-flow rate and on the quantity of heat to be absorbed. The evaporator fan motors often are located in the air stream and the heat from these motors is also absorbed by the air. However, this occurs before the air enters the cargo space and so does not affect the rise in the temperature of the air as it travels through the cargo space.

The original porthole containers were designed to have an air-flow rate of 60 air changes per hour (1000 cfm, 28 m^3/min or 0.47 m^3/s) and this also became the initial design figure for clip-on refrigeration units and integral containers. With this flow rate and with 1000 W of heat to be absorbed, the rise in temperature of the air from delivery to return would be 1.6°C. However, some integral containers do not meet this specification and have an air-flow rate of only 40 changes/hour. Thus, the rise in temperature (2.4°C) of the circulating air is higher in these containers. Many new containers have an air-flow rate of 90 changes/hour or higher; the rise in temperature of the circulating air would be 1.1°C or less. The spread in temperature of the produce must be at least as large as the rise in temperature of the air.

The T-bar floor channels allow air to flow beneath the produce, but a ceiling-gap (or head-gap) must be left between the top of the produce and the ceiling of the container. If this gap is too small, the resistance to air-flow will cause a decrease in the total air-flow rate and hence a higher spread in temperature of the produce. To avoid too must restriction of the air-flow rate, a minimum head-space gap of 50 mm must be left; the Department of Primary Industries and Energy (DPIE) regulations for export in containers specify a minimum gap of 50 mm, but a larger gap, up to 150 mm, would ensure that little restriction occurred.

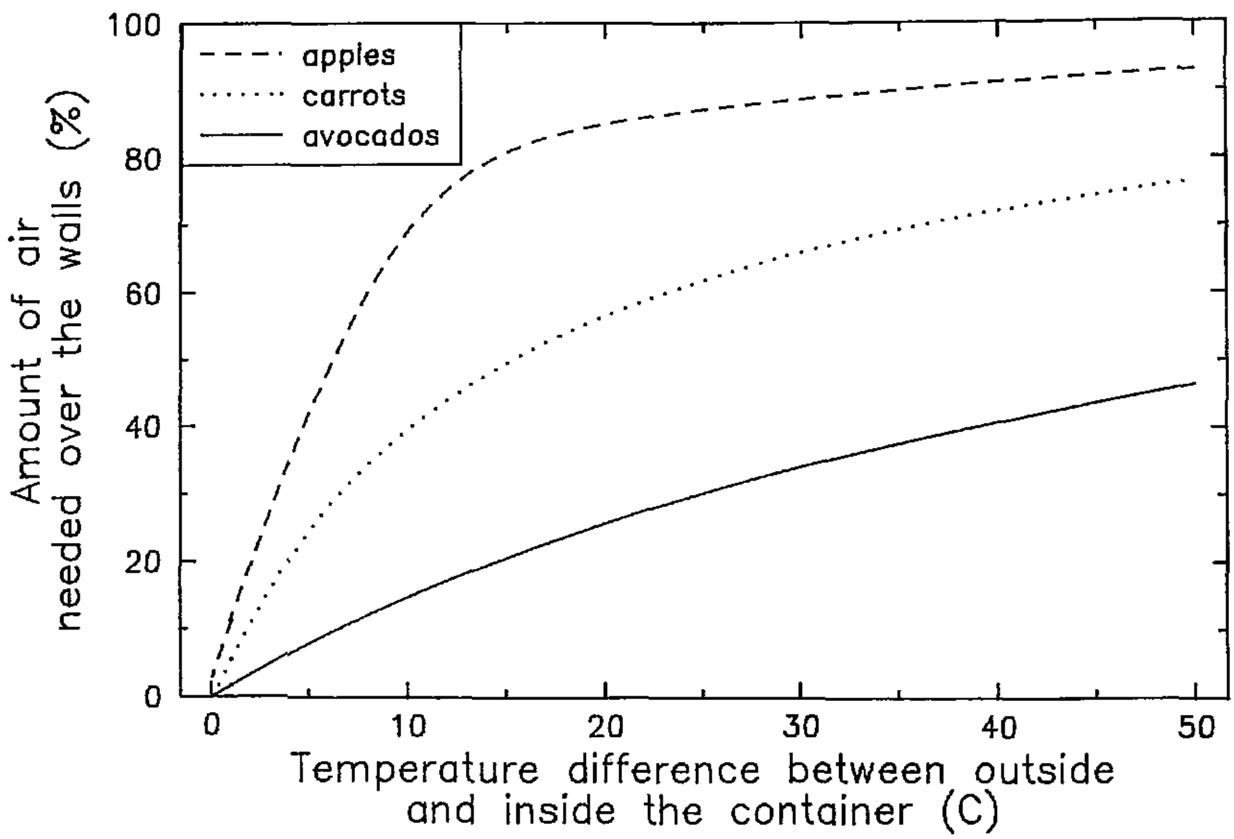


Fig. 4. ***Percentage of air needed over the walls of a container for equal removal of heat leakage and respiration heat against temperature difference between outside and inside the container for apples, carrots and avocados. (Heat leakage: 26W/C) (Heat of respiration: apples (0°C) 100W, carrots (0°C) 400W, avocados (10°C) 1500W)***

Air-flow distribution

Refrigerated air enters the cargo space (bottom or top) and flows over the internal walls, doors, ceiling, floor and between the produce, which is usually in cartons. The distribution of the circulating air between the flow paths over the walls and doors and those through the produce depends on the resistance of each path to the flow of air and hence upon the particular container and on the stowage pattern.

The most uniform temperature in the produce will be attained if the air is distributed such that the quantity of air flowing in each section is proportional to the quantity of heat to be removed. Thus, the air required in each section depends on the difference in temperature between the inside and outside of the container and on the heat of respiration of the produce in the container. (Values for heat of respiration of produce and recommended temperatures for transport are listed in the Code of Practice, Irving 1988).

The percentage of the total air-flow required to flow over the internal walls of a container to achieve this for apples, carrots and avocados is shown in Fig. 4 and is plotted against the temperature difference between the inside and the outside of the container. For temperature differences greater than 15°C for apples and carrots, over 50% of the air should be directed over the walls. For temperature differences greater than 30°C, over 70% should flow over the walls. It is only for produce like avocados which have high heats of respiration that less than 50% of the air should flow over the walls; for such produce, dunnage battens may be required to direct more air between the packages. However, the basic design determines to a large extent the way air is distributed in the containers; the use of dunnage battens or other stowage modifications have a lesser, though significant, effect on air distribution.

The gap left between the top of the produce and the ceiling of the container can affect not only the total flow rate, but also the air distribution. As the gap is reduced below about 50 mm, the increased resistance to air flow in this channel increases the likelihood that air will short-circuit through channels of lower resistance through the stow.

To ensure that the heat of respiration is removed from produce, it was originally thought that at least one face of every carton of produce in a container should be exposed to a moving air stream and, until 1988, this was a DPIE regulation for the export of horticultural produce in cartons in containers. This is achieved in practice by placing wooden dunnage battens vertically between every second tier of cartons down the length of a container; the battens are 10 mm thick and 30 mm wide. It has been found, however, that there are sufficient gaps naturally occurring between cartons to allow the flow of more than enough air to remove the heat of respiration and to do any cooling that may be necessary to bring the produce to the desired temperature (Irving 1982, 1984). However, dunnage must be placed between the last tier of cartons and the container doors to keep the stow tight and so prevent additional gaps occurring (Fig. 5). By removing battens from between cartons and placing battens in the door gap it was found that more air flowed to the door end of the container and the temperature of the usually warmer cartons near the door was reduced without affecting the temperature of cartons in the centre of the stow. There is still a DPIE regulation, however, requiring the use of battens for produce that is undergoing cold disinfestation to meet USDA requirements (Fig. 5).

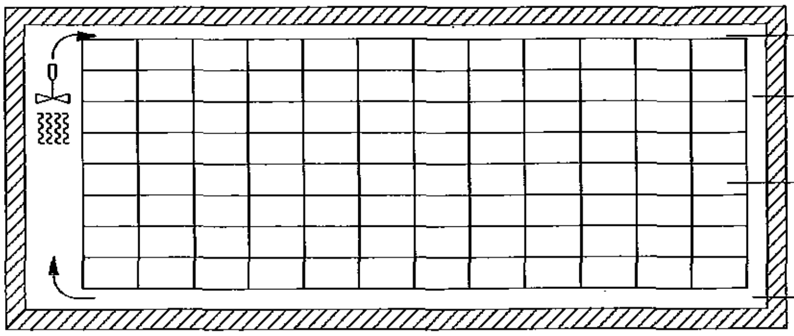
Temperature controller

The many temperature control systems with their different modes of operation, together with the temperature recorders, cause the most confusion when trying to understand refrigerated containers.

Set-point

The set-point is the temperature on which the pointer arm, dial or digital readout of the controller is set. However, the temperature which the refrigeration unit maintains in the cargo space depends on where the temperature sensor for the controller is placed. Most of the earlier, and some of the newer, refrigeration units are controlled from a temperature sensor located in the return air stream i.e., the air that comes back to the refrigeration unit after absorbing heat from the cargo space, and this is called return air control. When carrying chilled produce, many of the newest units are controlled by a sensor located in the delivery air stream i.e., the air leaving the refrigeration unit and about to enter the cargo space, and this is called delivery air control. These latter units retain a sensor in the return air for control when the container is carrying frozen produce. It must be emphasised that the set-point temperature is not be be confused with the carriage or produce temperature which will be discussed later.

Since the air warms up as it picks up heat as it moves through the container, then the temperature of the air at the point of return to



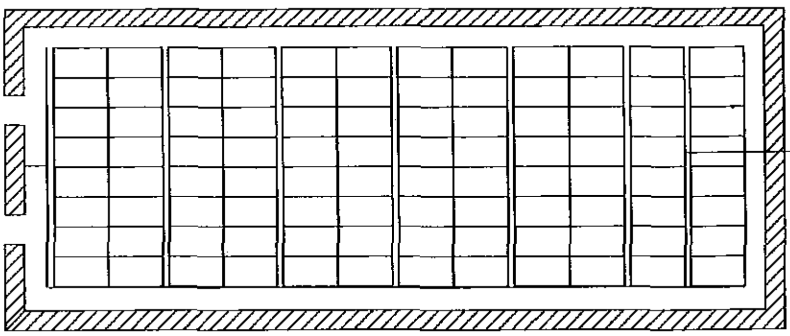


Fig. 5. Integral container with cartons stowed tightly with dunnage in the door gap and a porthole container stowed with dunnage battens to meet the USDA requirements for cold disinfesion for fruit fly.

the refrigeration unit is higher than the temperature of air entering the cargo space; this fact is reflected in the different set-points of the controllers. Thus, for the same average *temperature of produce in the container, the* set-point on a return air controller will be higher than that on a delivery air controller. Exporters need to understand this difference when they make requests to a shipping company regarding the setting on a container. Some exporters do not differentiate between the set-point and the produce temperature. Shipping companies likewise need to be aware of the kind of equipment they are using.

Return air control

Most units that are controlled from a return air sensor operate in an on/off mode. The controller commonly is an electro-mechanical device, incorporated in a single unit with a chart recorder (Fig. 6); the most common manufacturer is 'Partlow'[2] and this has become a general term to describe this type of *controller/recorder.* The control action is obtained by the expansion and contraction of mercury in a sensor bulb that is connected by a capillary tube to a piston; movement of the piston operates a microswitch. When the temperature of the return air falls to the set-point, the controller switches the refrigeration unit off. To avoid short-cycling i.e. switching on and off too frequently, the refrigeration unit does not switch on again until the return air temperature has risen by a fixed amount, commonly 1.1℃. Thus the return air temperature cycles by at least 1.1℃; the

[2] **Partlow Corporation, New Hartford, New York USA.**

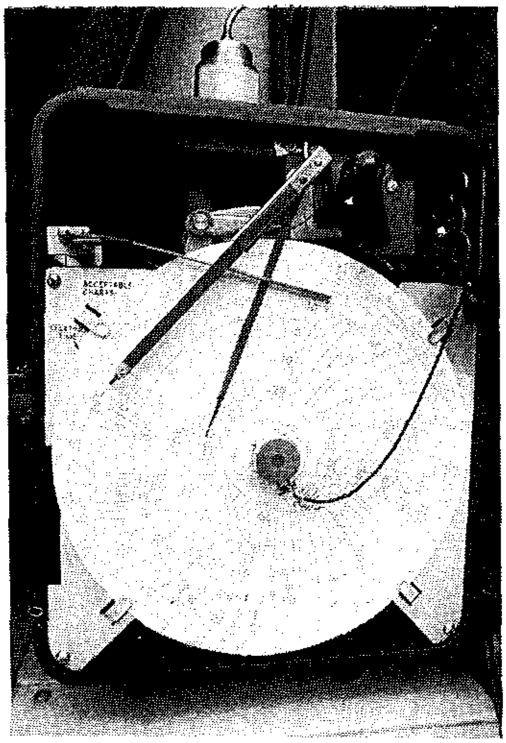


Fig. 6. Partlow recorder/controller

delivery air temperature will cycle much more than this — perhaps by 5° to 7°C. However, as the time for each temperature cycle is short, usually between 15 and 30 min, there is little effect on the temperature of produce in cartons.

To avoid possible freezing injury to produce carried near 0°C, a safety thermostat should be fitted in the delivery air stream; while most refrigeration units are fitted with such a thermostat, some are not and containers with such units should not be used to carry fresh produce. This thermostat turns off the unit if the delivery air temperature falls too low. These thermostats are commonly set at −2°C, but, in many containers, are fairly crude devices that cannot be set accurately, even with the use of an accurate, independent thermometer.

Delivery air control

Most of the units that are controlled from a delivery air sensor have some method of reducing the refrigerating capacity of the unit. If on/off control was used with full refrigeration capacity, then the unit may short-cycle and fail prematurely; some units are better designed for short-cycling than others. A common way of reducing the effective refrigeration capacity of the unit is to provide capacity control by hot-gas bypass where some of the hot refrigerant gas bypasses the condenser and is injected into the evaporator (Fig. 7). Thus the refrigeration unit runs continuously with an overall increase in power consumption compared to on/off operation and the temperature is controlled by how much hot-gas is mixed back. There are several ways of achieving this type of control. One simple method relies on a valve which operates mechanically from differences in pressure, that are related to temperature, between different parts of the refrigeration system. The valve is difficult to set and its setting alters with changes in the ambient temperature and thus gives poor control. Units with this mechanical valve require monitoring and adjustment throughout the transport journey. They are not true delivery air controllers because they always operate in conjunction with a return air controller that has overriding control; this is a type of combined control.

True delivery air control is provided by those units which use a sensor in the delivery air stream to regulate the amount of hot-gas bypass. Different systems use different methods: one system modulates a three-way valve, another pulses two on/off valves while another pulses a single bypass valve. When properly set up, these controllers can give an accuracy of ±0.5°C and require little checking or adjustment during transport.

Another form of capacity control is achieved by the use of suction throttling. Again the unit runs continuously with capacity reduced by a

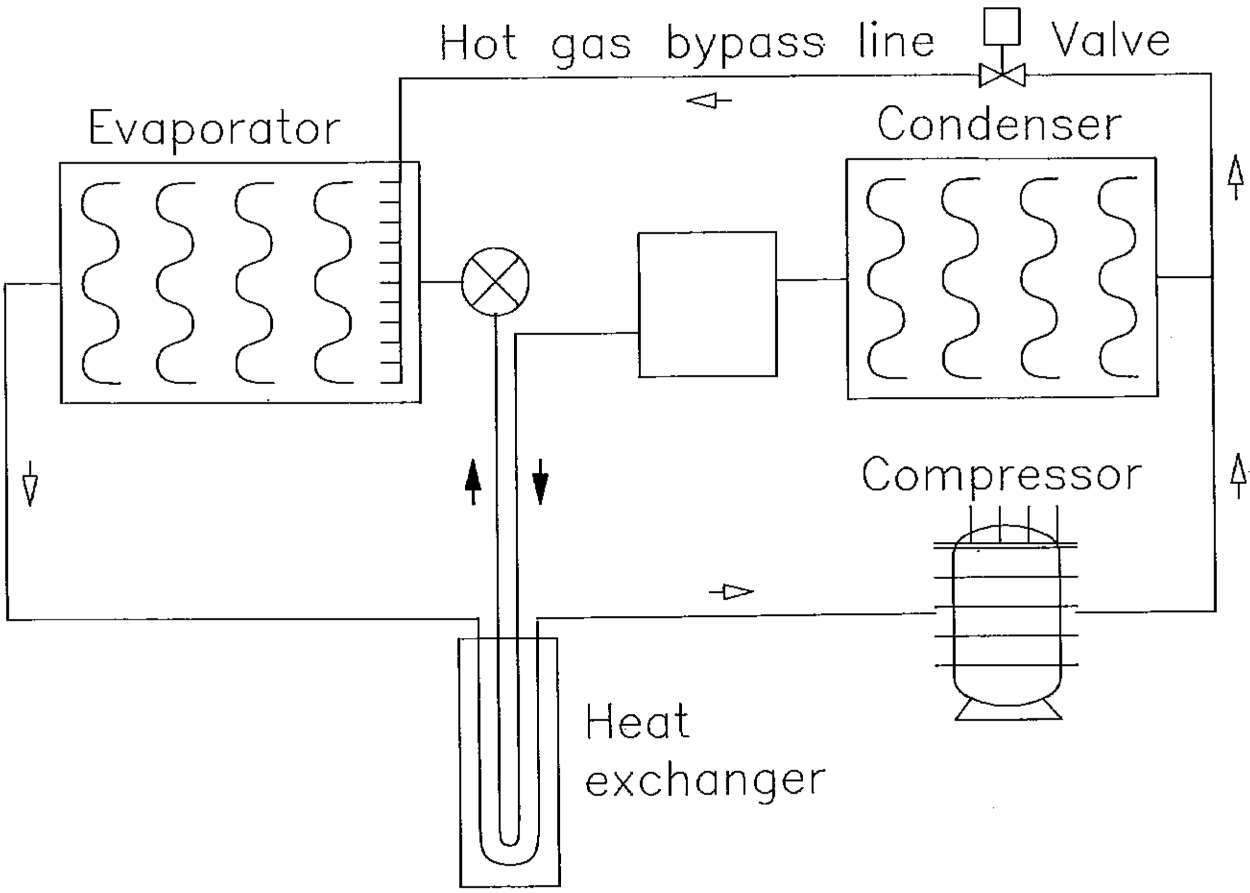


Fig. 7. Schematic drawing showing line for hot-gas bypass from the condenser to the evaporator. With this type of control, the refrigeration unit operates continuously on full power.

valve which controls the flow of refrigerent gas to the compressor; the power consumption is much higher than with on/off control, but less than with hot-gas bypass.

New units, now being developed, will provide complete capacity control through continuous control of the speed of the compressor motor; this will result in much lower power consumption.

Combined control

Some refrigeration units have an electronic delivery air controller and a mechanical return air controller that operate together. Air is delivered to the cargo space at the temperature setting on the delivery air controller, but if the temperature of the return air falls to the temperature on the return air controller then the unit cycles on and off. While in theory this may seem to offer the best from both types of control, in practice this is not usually the case. The electronic delivery air controllers offer much more accurate control than the mechanical return air controller, but this accuracy often is lost due to a poorly set or calibrated return controller; the produce temperature may then be significantly higher than would have been the case if the return air controller was not in operation.

Another, inadvertent and inaccurate type of combined control can occur with containers fitted with mechanical safety thermostats. When containers with return air control are stowed with warm produce, the refrigeration unit operates continuously as the produce is cooled to the desired transport temperature. The return air temperature may remain above the set-point temperature for several days while the delivery air temperature may drop below the freezing temperature of the produce. The safety thermostat then operates to provide on/off control throughout the cool-down period. While this is satisfactory during cool-down, if the safety thermostat has been set inaccurately then the unit may continue to operate in this manner for the whole journey with the result that the produce is carried at a higher temperature than desired. This same situation can occur with containers fitted with hot-gas control of the delivery air.

Defrost

During operation of the refrigeration unit, water vapour is transferred from the cartons, produce and the air to the refrigeration evaporator coils. If the temperature of the coils is below 0°C then frost builds up and the air circulation rate and refrigeration efficiency falls. Most units are fitted with timers to automatically give a defrost at set periods — commonly twice a day. Some units are fitted with a pressure sensor that gives a defrost when the resistance to air flow across the evaporator reaches the pre-set figure. Some units are fitted with both systems. Electrical heaters or hot-gas are used when a defrost is carried out and the air circulation fans are turned off so that the heat goes into melting the ice and not into heating the cargo. The temperature in the evaporator section goes up and this can usually be seen as a sharp rise and fall in temperature on the recorder chart. The melted ice from the coils falls into a tray and then runs outside. Sometimes the outlet blocks, and water accumulates on the container floor with damage to the cartons and produce. In the worst case, the water on the floor can freeze and block the air flow with a consequent rise in temperature of the produce. Blocked outlets should not occur if they are properly cleaned during the pre-trip procedure.

Large amounts of water can be transferred to the evaporator coils during the initial period of operation of the refrigeration unit as moisture is removed from packaging materials and perhaps from the produce. There may be 800 kg of fibreboard packaging with a moisture content of 10% in a container. Reducing the moisture content to 9% is equivalent to the removal of 8 litres of water. It 12 tonne of produce loses 0.1% of its moisture this is equivalent to about 11 litres of water. Air freshening also introduces moisture into a container and up to 3 litres/day may be deposited on the evaporator for an air freshening rate of 1 air change every 4 hours. The actual amount depends on the moisture content of the air and the temperature of the evaporator coils.

Container temperature recorder and produce temperature

Most refrigeration units are fitted with a mechanical circular chart recorder, 150 or 200 mm dia., that records, in almost all cases, the temperature of the return air; there are, however, an increasing number of charts that record the delivery air temperature. Commonly, the recorder is combined with an *on/off controller*. The paper chart is pressure sensitive and a record is made by a mechanical lever making contact with the paper. The lever is operated through a series of linkages by a mercury operated piston as described earlier.

These mechanical recorders can be in error commonly up to 1°C and occassionally by 2°C or higher. These errors can be critical when attempting to ship produce near 0°C. Small errors occur through wear in the mechanical linkages of the system. The larger errors are usually the result of poor adjustment during the pre-trip procedure.

The temperatures indicated by a properly adjusted recorder, with a sensor in the return air, should be close to the average temperature of the bulk of the produce. However, this will not be the case if air is short circuiting in the cargo space due to poor stowage of the produce or if the total air flow is low. Thus, it is possible for a recorder to give a steady trace at the desired carriage temperature, while the temperature of the bulk of the produce is several degrees higher.

For units operating with return air control, the recording temperature and the set-point temperature should be the same. However, this will not be the case if the return air controller is being over-ridden by a safety thermostat in the delivery air. For units operating with delivery air control, the recorded temperature will be higher than the set-point temperature. One problem that can occur with delivery air control is that an inexperienced operator may set the controller at the desired produce temperature. This will result in the temperature of the bulk of the produce being 1° to 2°C higher than the desired temperature; this may mean an unacceptable loss of quality during the journey.

New controllers and recorders

With advances in electronics and microprocessors, some refrigeration units have already been fitted with controller/recorders that have digital readouts and store delivery and return air temperatures in memory, along with other information for later retrieval. This will allow much more accurate records to be obtained as well as the potential for more reliable control. There are also developments that will allow information about individual containers to be obtained through pulses down the power lines. This will enable integral containers to be monitored from the ship's control room.

Pre-trip inspection

Each container, before being sent out to be loaded with produce, should undergo a complete check — pre-trip — of the refrigeration unit to ensure it operates correctly. Part of this procedure is to check and adjust, if necessary, the temperature control and safety thermostat and the recorder. The serviceman places a temperature sensor from his own instrument in mechanical contact with the sensor that is being checked and makes any adjustments needed. Thus, the accuracy of the serviceman's instrument and the care with which it is positioned is of prime importance if a correct calibration adjustment is to be made.

The commercial pressure under which some pre-trip servicemen operate sometimes means that proper care is not taken. They may not couple the sensor from their instrument sufficiently close to the sensor being checked or they may not wait until temperature equilibrium has been reached. They may not check the calibration of their own instrument often enough and this may result in wrong adjustments to the control unit on the container. The most critical temperature for the carriage of produce is near 0°C, which is also the most readily obtainable and accurate calibration point. It can be obtained by using a wet, crushed ice mixture in a Dewar flask (e.g. 'thermos'): if the wet mixture is firm, the sensor may be embedded and tamped down and the reading taken. If ice cubes are used or the mixture is a slurry, the sensor must be surrounded by ice, not the warmer water below the ice, and the mixture must be stirred to be sure of obtaining a true ice temperature.

Increased attention should be given to the procedures carried out during a pre-trip inspection. With the decreasing number of personnel on vessels, there is less time available to give attention to refrigeration units that may be operating incorrectly. Preventative maintenance must become standard practice so that the refrigeration units will operate trouble free during a voyage. New diagnostic equipment coupled with a re-design of the refrigeration units should make preventative maintenance more feasible in the future.

Temperature distribution in the produce

The temperature difference between the delivery and return air has been discussed earlier. The actual spread in temperature of cartons of produce is much higher than this because, in practice, the air is not distributed in proportion to the amount of heat it has to absorb. In a trial shipment of 15 integral containers to Hong Kong in 1982, the spread in temperature in cartons of pears ranged from 1° to 5°C when the ambient temperature was 12°C to 1.5° to over 6°C when the ambient temperature was near 30°C (Irving 1982). A spread in temperature of over 3°C is unacceptable for produce like pears. The temperature record for two containers is shown in Fig. 8. Note how the temperature spread markedly increases in one container as the heat load on the container increases, but not in the other container.

The different spreads in temperature can be partly attributed to different container types but there were significant differences between similar stows in similar containers. Higher spreads in temperature are found usually in containers that have lower air flow rates or have a poor air flow distribution; some containers are inherently unsuitable for the more sensitive horticultural produce and some are unsuitable for all horticultural produce — they are only suitable for frozen goods.

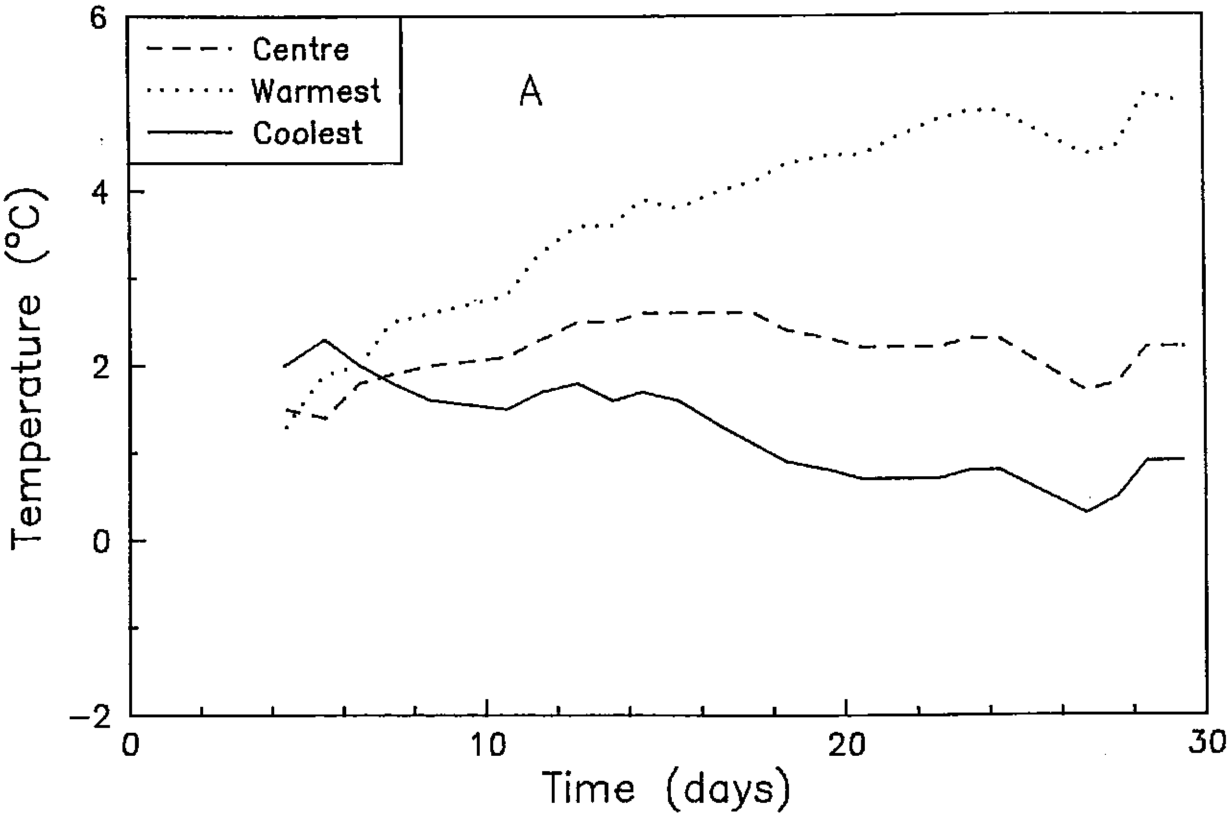
In most cases the warmest produce in integral or clip-on containers is located near the doors: for a container with bottom air delivery, the warmest region is in the top layer of cartons, and for top air delivery is in the bottom layer. It is important to recognize this difference if a sensor is being placed to monitor temperature. Removing the dunnage battens from stows of produce directs more air to the door end of the container and cools the warmest cartons, so reducing the temperature spread.

Thus, there is no such thing as a single produce temperature during transport — one can only refer to the mean (or average) temperature. This is illustrated in the histogram in Fig. 9, which shows the difference in the spread in temperature between a container with poor air flow and one with high air flow.

Independent recorders and monitoring

Many exporters like to have an independent record of the temperature in a container during transport. One way of doing this is to place a portable recorder in with the stow, though this is generally discouraged by the shipping companies because of their possible use in insurance claims. The make of recorder used most commonly is a 'Ryan'[3] (Fig. 10), which is leased rather than bought. This recorder uses a battery to drive a pressure

[3] **Ryan Instrument Inc., South Kirkland, USA. (Australian agents: Craig Mostyn, South Melbourne).**



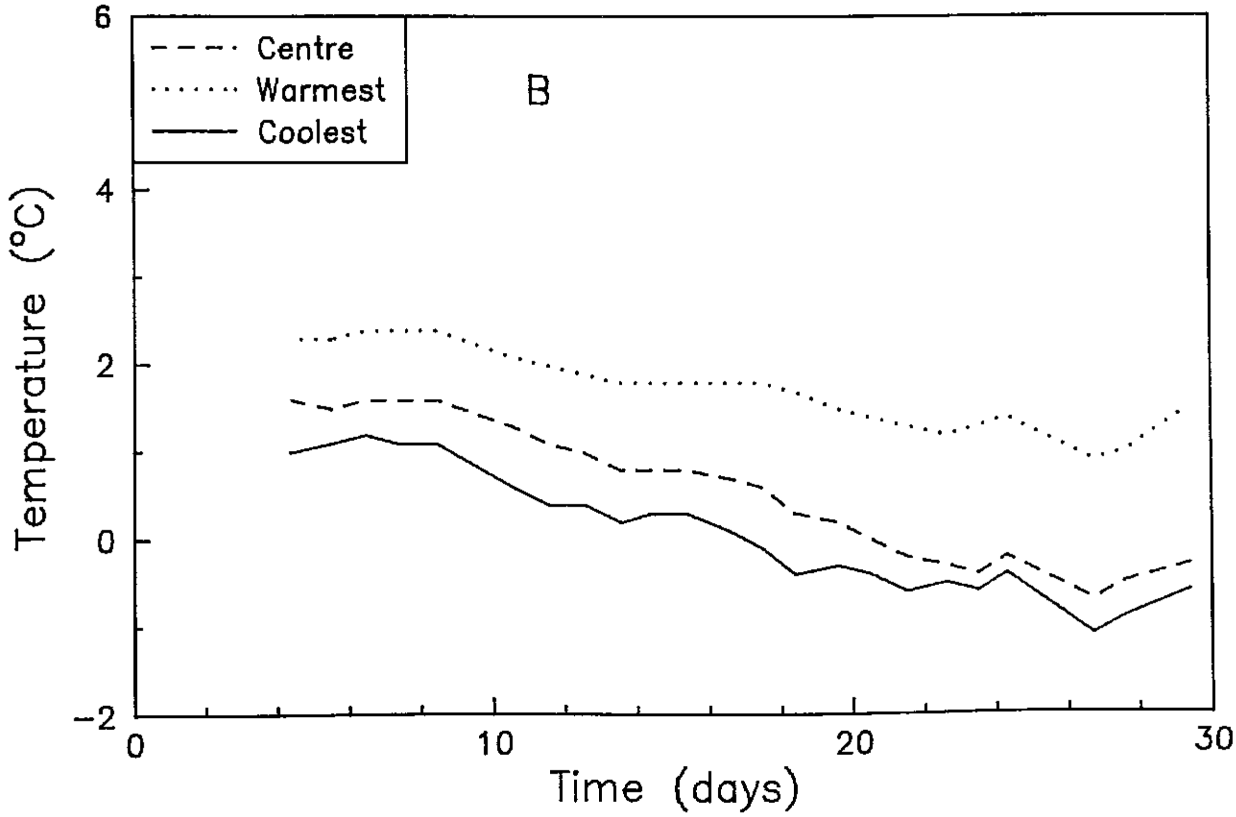


Fig. 8. Temperature record of the coolest, warmest and centre cartons of pears during shipment from Shepparton (Vic., Australia) to Hong Kong in a container with poor air distribution but reasonable temperature control (A) and in a container with good air distribution but poor temperature control (B).

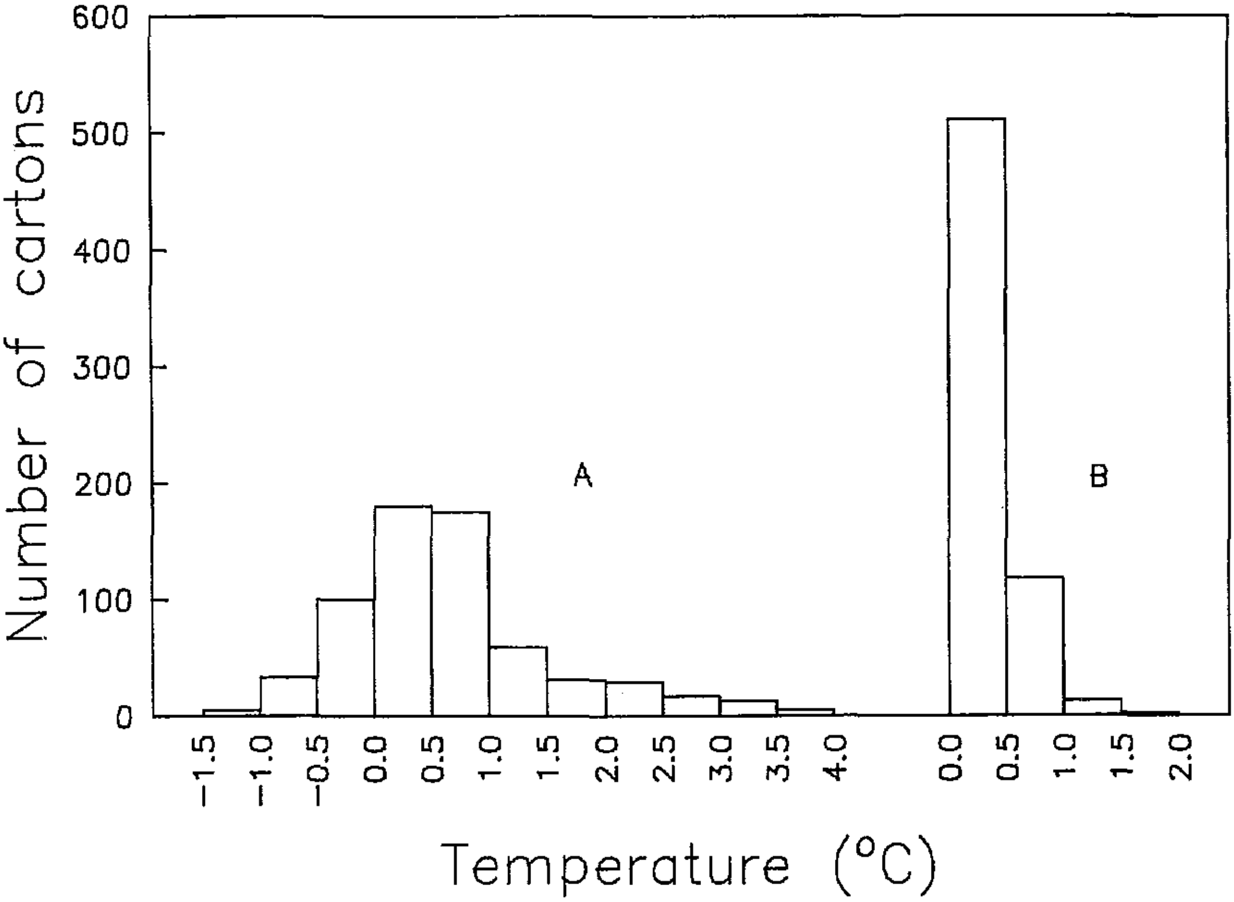


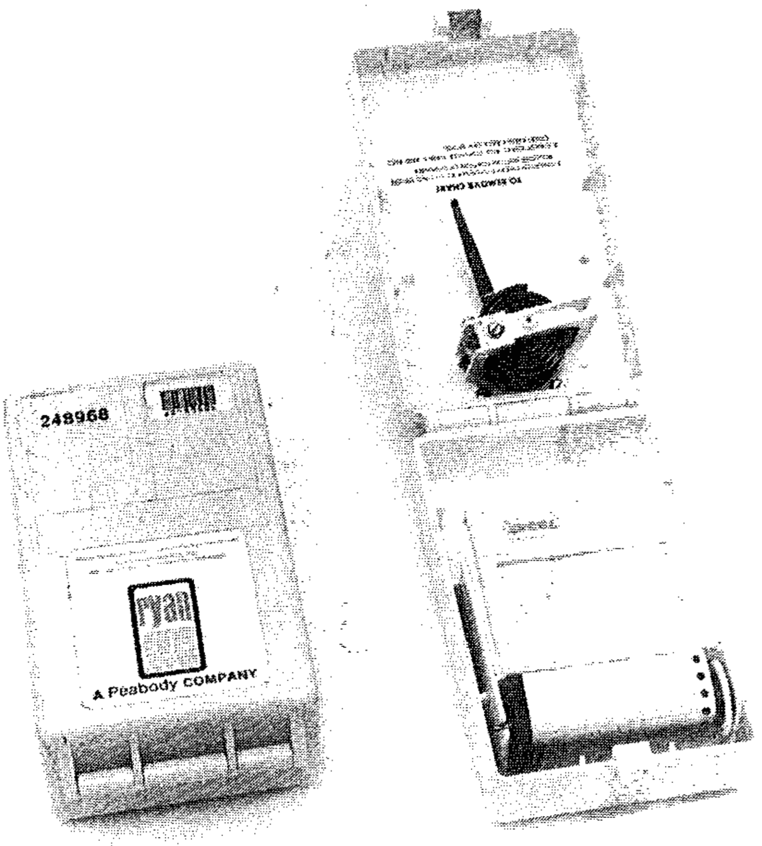
Fig. 9. **Estimated number of cartons in each 0.5°C interval for an ambient temperature of 35°C for a container with poor air flow and distribution (A) and a container with good air flow and distribution (B).**

sensitive chart. A pen, operated by a metallic spiral, makes a recording on the chart. The 'Cox'[4] is a similar type of recorder which can be bought or leased. Unfortunately, exporters have neither pooled the information obtained from these recorders nor put their own information systematically together and so the full potential of these recorders has not been realised.

There is disagreement about where such recorders should be placed. Part of the disagreement is due to a desire to record different things and part due to ease of recovery of the recorder. If there is concern for freezing the produce, then the recorder should be placed near where the delivery air stream enters the container, either in the air stream or in a package. Thus, for a container with top air delivery, the recorder should be placed on the top of the stow or in a top package or stuck to the ceiling near the refrigeration unit end. For a container with bottom air delivery, the recorder should be placed in a corresponding position at floor level. If there is a desire to record the mean produce temperature, then the recorder should be placed in a package near the centre of the stow. If there is concern that packages near the door are not getting sufficient air and may be too warm, then the recorder should be placed near the door — at the bottom for a top air delivery container and at the top for a bottom air delivery container.

To avoid possible confusion between top and bottom air delivery containers in placement of the recorders, it would be best to place the recorders at half height in the container. For ease of recovery, it would be best to place the recorders near the door. Thus the best position would be in the second last tier of packages at half height in the centre-line of the container.

[4] Transit Services Inc., Long Beach, USA. (Australian agents: Geoffrey Thompson & Growers Co-op. Co. Pty. Ltd., Melbourne)



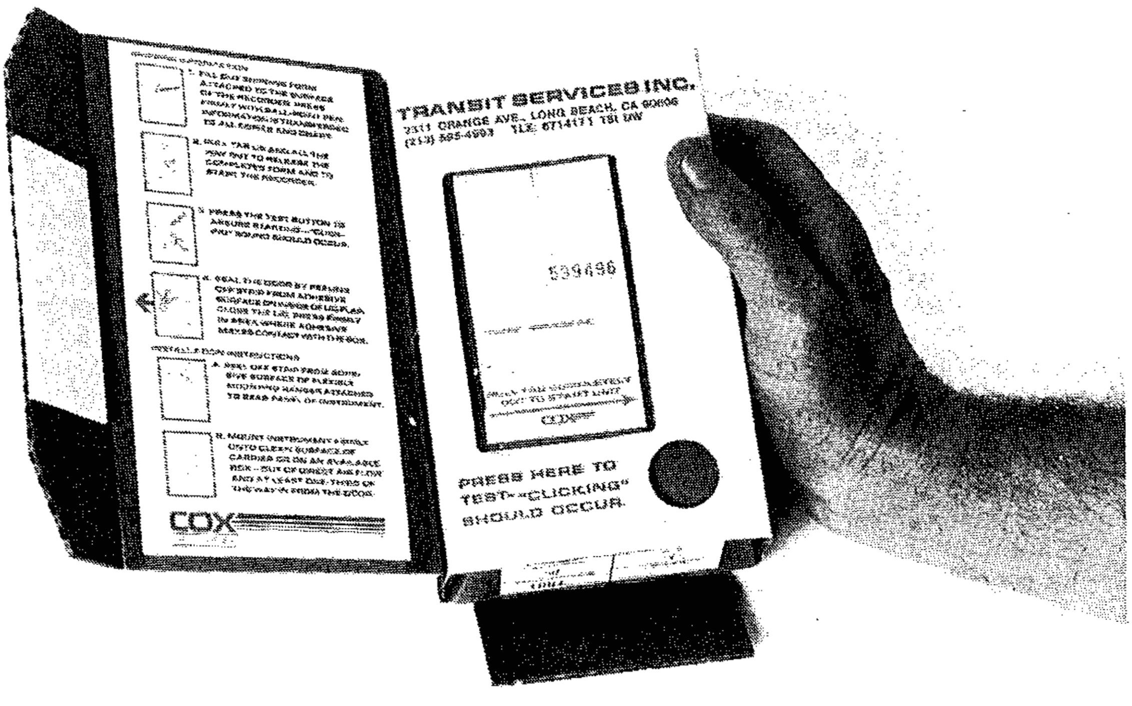


Fig. 10. Portable recorders commonly used to give an independent record of temperature in containers.

However, because of the need for simplicity and of having a common measuring point with one of the positions required for USDA monitoring, the recommended position is in the top package in the last tier and in the centre-line of the container. The package must be clearly marked to ensure that the recorder is recovered at outturn, and somebody must be given the responsibility to forward the recorder to the appropriate place.

The temperature recorded in the recommended position may differ by up to 2°C, higher or lower, from the average temperature of the produce and the temperature on the return air recorder. The accuracy of these recorders depends on how well they have been adjusted during calibration but should be within ±1°C. They should be regarded more as devices to record 'catastrophies' rather than to give representative temperature records.

Another type of recorder marketed especially for measurements during transport is the 'Autolog'[5]. This instrument has 4 sensors so that more than one point can be measured. The recorder can be bought or hired and a service is offered where the company processes the recorded data and issues a report. The claimed accuracy is ±0.2°C. This recorder is much more expensive to hire than a 'Ryan', but more information is obtained. There are various other recorders on the market, both single and multipoint, that can be used to monitor container temperatures.

Temperatures recorded by independent internal devices are accessible only at the end of the journey and no corrective action can be taken if the container is mal-functioning. An alternative is to place in the container a sensor that can be monitored from the outside so that corrective action can be taken if necessary. One method is to place a thermocouple wire, usually type T, in a package and bring the wires out through the door seals and along the roof of the container to the refrigeration end — this will allow readings to be taken while the container is at the terminal or on the ship. The recommended position for the measuring junction is in the top package in the last tier in the centre-line of the container. Care must be taken to ensure that accurate readings are obtained and that a type T instrument is used with type T wire (Sharp 1988). The readings obtained from this thermocouple must be interpreted with care, especially during the initial period after the refrigeration unit is switched on. If the measured temperature indicates that this package is too warm, then the set-point must not simply be reduced if there is no measurement of the coolest carton, otherwise the coolest carton may freeze.

[5] **Remonsys Ltd, Bristol, UK. (Australian agents: Co-ordinated Thermal Systems, Clayton Nth.)**

Stowage of produce into containers

Ideally, the container should be sealed to a coldroom air-lock and produce loaded without contact with the ambient air. As this is not the case at the moment, containers should at least be put under cover away from direct sunlight. There is no need to pre-cool the containers before loading as the heat from the container will warm the cartons against the walls by only about 0.5°C; the extra water that condenses in the container will end up on the evaporator coils when the unit is started and may cause the unit to turn off more often for extra defrosts. It is more important that the container is loaded quickly, the doors closed and the container despatched immediately to the terminal. Likewise, pallets of produce should not sit outside the coldroom unnecessarily while waiting to be loaded into the container. All operations should be in accordance with the Code of Practice (Irving 1988).

The internal dimensions of containers differ from one type to another and from one manufacturer to another: porthole containers are longer internally than integral containers and the depth of the refrigeration unit in some containers is much less than in others. Carton sizes also differ for different produce, and thus it is not possible to specify one standard stowage pattern. Suggested stowage patterns are given in a manual published by DPIE (Cumming 1988), and should be studied carefully by all those who wish to export in refrigerated containers.

It is important to determine the most efficient pattern before stowage is commenced; it may be necessary to lay out part of one layer of cartons on the container floor. For stability of the stow it is important that a turned-tier (cross-row) of cartons is not placed against the doors, but is placed one or two tiers in from the doors. Cartons that are badly made or are out of square or are bulging because of being overfilled or wet can mean an expected stowage pattern is not attained. Bulging cartons also cause additional air gaps that can result in short circuiting by the refrigerated air. A bulging container can cause similar problems. Except for produce undergoing cold disinfestation to meet USDA requirements, cartons should be stowed tightly together and vertical dunnage should be placed between the end of the stow and the doors to fill the gap and to keep the stow tight during transport.

As explained earlier, a 50 mm gap must be maintained between the top of the stow and the ceiling of the container to ensure proper circulation and distribution of the air. This has been included in the DPIE Export Control (Fresh Fruits and Vegetables) Orders, but sometimes this is ignored, with the rationale that the stow will settle. Settling of the stow, especially for cartons of apples and pears, cannot be relied upon to open up this gap, and a gap of 50 mm should be kept across the entire stow at the time of packing. This gap is a minimum requirement and should be treated as such — a wider gap will ensure better air distribution and is undoubtedly essential to gain the full benefit from the containers fitted with units that give high air circulation rates.

Some containers become warped through mis-handling and this may create stowage problems across the container if the walls are bowed or in maintaining the 50 mm ceiling gap if the roof is bowed. If the walls bow out to such an extent that the stow would be very loose, the container should be rejected. If the ceiling bows in too much, a layer of cartons may have to be left out.

Some containers are fitted with air delivery and return openings in only one half of the end wall. In these containers, special stowage may be required to distribute air more uniformly across the container. If no air channels are fitted in the other half of the end wall, then air channels must be created by stowing the cartons that are immediately adjacent to the end wall, across instead of lengthways in the bottom and top layers (Cumming 1988).

Modified atmosphere transport

At present there is much interest in the use of modified atmospheres (MA) or controlled atmospheres (CA) during transport. However, for most horticultural produce, there appears to be little justification for this. Indeed, two members of the Transfresh Corporation (a commercial firm involved with MA transport) made the comments: 'if produce was carried at ideal temperatures there probably would not be anyone in the MA business for transit of produce' (Woodruff 1977) and 'one hidden benefit is that the attention given to the commodity being transported can frequently result in better handling throughout the distribution chain, augmenting the returns available from use of MA' (Wolfe 1980). Ensuring proper handling procedures and temperature maintenance will be of more benefit for most of Australian traditional horticultural exports than the use of MA with its additional costs.

For certain highly perishable produce, however, MA or CA may have a place. Produce such as asparagus, berries, stone fruits, mangos, avocados and cut flowers are, at present, transported by air. If larger quantities of this produce are to be exported, then shipping must be used and MA techniques may provide the required extension of storage life. A large amount of laboratory work is still needed to determine suitable MA conditions.

The use of highly specialized containers to provide MA conditions seems unlikely because of the cost. Modifications to allow conventional refrigerated containers to be used on a 'one-trip' basis is a more likely development. Already some shipping companies are specifying a very high level of gastightness in new containers. This is achieved using a track to allow a plastic curtain to be fitted at the door end. Transfresh Pacific, a company based in New Zealand, has conducted commercial shipping trials using active control of oxygen and carbon dioxide levels, achieved using an atmosphere control module fitted to the container for the trip. Respiration of the produce consumes oxygen and produces carbon dioxide. Excess carbon dioxide is removed by lime, and fresh air is admitted, as needed, to prevent the oxygen level falling too low.

High quality produce at loading

A major requirement for maintaining high quality during export of perishable produce is that the produce should be pre-cooled to the desired carriage temperature before stowage in the container. Apples and pears are carried near 0°C. While Australian regulations may allow apples to be loaded at temperatures up to 5°C and some pears up to 4.5°C, it is clearly bad practice to do so. At 5°C, apples are ageing about twice as fast as at 0°C. When stowed in a container, warm produce can take up to three weeks to cool to the desired temperature, depending upon the container, the position of the produce in the container and on the ambient temperature.

Thus to ensure the higest quality on the overseas market, it is essential that produce be:

(1) harvested near optimum maturity
(2) handled carefully to avoid mechanical damage
(3) cooled promptly after picking
(4) graded for quality and approved postharvest treatments applied
(5) kept under optimum storage conditions

(6) stowed in the container at the desired temperature for transport and the container delivered to the export terminal immediately.

Poor quality produce at outturn

The poor quality of produce at outturn from some containers remains a problem for the industry. The initial quality of the produce as well as the performance of the container both contribute to the quality at outturn.

It is still common practice by many exporters to load produce at the wrong temperature i.e. at temperatures considerably higher than the desired temperature during transport. It is not uncommon for produce to be loaded at the maximum permissible temperature (or slightly above) even though this is several degrees above the desired temperature for transport. Sometimes the temperature is excessively high e.g. for a trial shipment in 1984, pallets of WBC pears at 7°C were presented for loading. On the other hand, for a trial shipment in 1983, partly frozen pears were presented for loading. While DPIE inspectors are present during loading, they cannot inspect every pallet and indeed should not carry the responsibility of quality control. While the above examples may represent extreme cases, they do indicate that exporters need to work positively to maintain good practices.

Poor stowage of cartons into the containers can also cause problems. Sometimes in an attempt to achieve a full stow with cartons that are overpacked or with a container with a sagging ceiling, cartons are stowed tightly to the ceiling or with a gap that is less than 50 mm. This restricts air circulation and results in produce at the door end of the container being carried at a higher temperature than desired. This effect will be even greater if the cartons bulge and allow the air to short circuit through the resultant vertical gaps near the refrigeration end of the container.

Frozen produce at outturn can be the result of a thermostat on the refrigeration unit being incorrectly adjusted, in which case only part of the stow is usually affected. Part of the stow can freeze in containers with return air control if the produce is loaded warm and the safety thermostat in the delivery air is incorrectly set. Produce found to be hard frozen at outturn is usually the result of the thermostat being set for frozen produce.

Produce that outturns in an advanced state of maturity may have been carried at too high a temperature as the result of a thermostat that was poorly adjusted. If only part of the stow is affected then the air flow in the container was inadequate or poorly distributed, perhaps as a result of packages stowed too closely to the ceiling. There are some refrigerated containers that should not be used for produce that is to be transported at temperatures at or below 0°C.

Produce that has a good appearance can be loaded at the desired carriage temperature into a container and be transported at the correct temperature and still outturn poorly. In 1982, a container load of Packham pears reached Hong Kong in an advanced yellow, soft condition despite being loaded and carried at the correct temperature. As the transport system was not at fault, the pears were presumably mistreated at an earlier stage of handling.

TABLE 2

Checklist when using refrigerated containers

When ordering containers
- Specify the produce to be carried
- Specify the desired produce temperature during transport, not the refrigeration unit set-point

Before commencing to load
- Check date on pre-trip sticker: reject if sticker is not current i.e. more than 30 days old
- Inspect container for bowed walls or ceiling: reject if bowing would create large gaps in stow
- Check thermostat setting: place clear note on documentation if the setting is far from the desired produce temperature. If the unit is to be operated at the packing shed after loading, check proper thermostat setting with the shipping company. (note: the correct setting depends on the type of control system)
- For horticultural produce, ensure that the ventilation control is opened
- Ensure portholes are closed on porthole container
- Work out the stowage pattern before loading starts
- Place containers up to a coolroom air-lock or under cover

While loading
- Bring produce from coolstore only as required
- Ensure that produce is at the correct temperature for transport i.e. measure with a calibrated thermometer
- Complete loading without delays. If delays occur, close container doors and return produce to coolroom
- Do not run refrigeration unit while container doors are open
- Stow without dunnage but place dunnage in door gap to keep stow tight (NB Use dunnage as required for produce undergoing cold disinfestation for USDA)

After loading
- Complete documentation with full description of the produce (e.g. WBC Pears not simply Pears) and the desired produce temperature during transport and despatch with container
- Send container directly to container terminal for immediate connection to power or connect to power on site

Most produce needs some fresh air ventilation during transport to avoid build-up of carbon dioxide or ethylene. Some containers do not provide fresh air ventilation and should not be used for the carriage of horticultural produce. Most containers have a ventilation facility that is opened when required. Poor outturns may result from inadequate ventilation.

A checklist, given in Table 2, is a reminder of some things which exporters should check to minimize the chances of poor outturns. The Code of Practice for Handling Fresh Fruit and Vegetables in Refrigerated Shipping Containers should, of course, be followed (Irving 1988).

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Thermophilic bacteria and food spoilage

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Introduction

The term thermophile has acquired several definitions and is used in many different ways. There is a tendency to describe as thermophilic any microorganism that grows at temperatures considered high in whatever context is being discussed. Most of the bacteria discussed in this paper are thermophilic by the most stringent criteria. They are well adapted to life at high temperature, with optimum and maximum growth temperatures of at least 50°C and 60°C respectively. Many strains fail to grow, or grow very slowly, at 37°C or below.

Thermophiles have been prominent as spoilage agents of heat processed, commerically sterile foods. Thermophiles were once considered the most important cause of spoilage of canned foods, particularly vegetables. As the incidence of thermophilic spoilage has declined over the past few decades, awareness of their potential importance has also decreased. Thermophiles still present problems for food processors. This paper describes the species of thermophilic bacteria important in food spoilage, their distribution and behaviour in food, and methods for their detection and control.

The thermophiles involved in food spoilage are sporeformers, members of the genera *Bacillus, Clostridium,* and *Desulfotomaculum*. Table 1 lists the species to be discussed in most detail, with a guide to their growth temperatures. The temperature range for growth varies with the strain, the growth conditions, and the way in which minimum temperatures are defined, leading to conflicting reports. For example, there is evidence that some strains of *C. thermosaccharolyticum* can grow and spoil canned foods at 29°-30°C (Matsuda *et al.* 1985).

TABLE 1

Thermophilic bacteria important in food spoilage and their approximate growth temperatures (°C)[1]

	Minimum	Optimum	Maximum
B. stearothermophilus	35	50-65	70-77
B. coagulans	15-20	35-42	55-60
C. thermosaccharolyticum	35	55	67
D. nigrificans	35	55-58	60-70

[1] Data collated by Wiegel and Ljungdahl (1986)

These organisms are able to spoil heat processed foods because of the considerable heat resistance of their spores. The chain of events that leads to spoilage of canned foods by thermophiles is as follows. Spores of the thermophile must be present in the unprocessed product at levels that will allow some spores to survive the heat process. The chemical composition of the processed product (e.g. its pH) and the temperature at which it is stored must then allow germination and outgrowth of the surviving spores and subsequent vegetative growth to occur.

The heat resistance of the spores of thermophiles is related to their adaptation to growth at high temperatures, which requires their enzymes and other components to be intrinsically more heat-stable then those of mesophiles. When the protective mechanisms of the spore are added to this high intrinsic stability, the result is a very heat resistant organism. Work at this laboratory summarized in Figure 1 has shown that there is a close relationship between spore heat resistance and maximum growth temperature for a range of *Bacillus* species (Warth 1978).

The heat stability of the spores of important thermophiles is illustrated in Table 2. Specific points to note about these data are:

1. The heat resistance of spores of a bacterial species may vary widely, depending on such factors as the strain tested, the growth and sporulation conditions, and heating conditions.
2. The D value given for *C. thermosaccharolyticum* is considered unusual. Values ten or twenty-fold lower are more common (Ashton 1981).
3. Values for *B. coagulans* are for acid-tolerant strains that are not particularly

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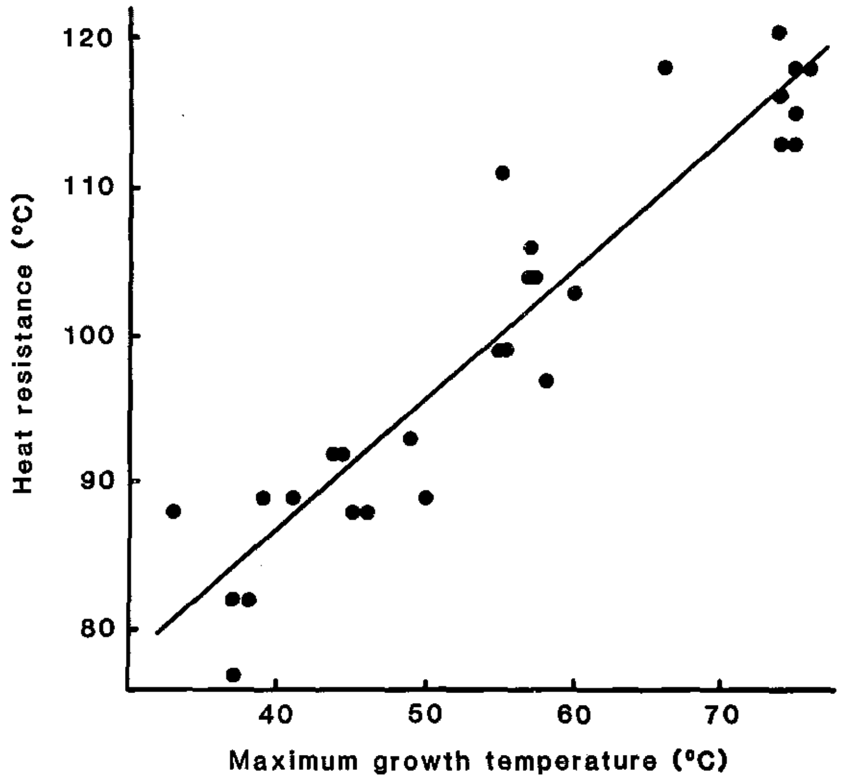

Fig. 1. **Relationship between maximum growth temperature and heat resistance of 28 strains of *Bacillus*. Heat resistance is expressed as the temperature at which the D value was 10 minutes. Data from Warth (1978).**

TABLE 2

Heat resistance of thermophile spores in aqueous media

	Temperature (°C)	D value[1] (min)	Reference[2]
B. stearothermophilus	121	2.5-14	1
B. coagulans	99	3.1-9.5	2
C. thermosaccharolyticum	124	68-76	3
D. nigrificans	121	13-54	4

[1] Time to reduce the viable count to one tenth of the initial value at a given temperature.

[2] References: 1, Russell (1982); 2, Kosker *et al.* (1951); 3, Xexones *et al.* (1965); 4. Donnelly and Busta (1980).

thermophilic. *B. coagulans* includes a diverse range of strains and higher values have been recorded for other strains.

4. Heat processes that cause a substantial reduction in *C. botulinum* have a much smaller effect on thermophiles.

Bacillus species

The thermophilic members of the genus *Bacillus* important in spoilage of canned foods are classified within the relatively heterogeneous species *B. stearothermophilus* and *B. coagulans* (Claus and Berkeley 1986). These bacilli typically ferment carbohydrates with the production of acid but little or no gas, thus souring the product but not swelling the container (flat sour spoilage).

B. stearothermophilus will not grow at pH values below about 5.3, and accordingly spoils only low-acid canned foods. *B. coagulans* can grow at pH values close to 4 and principally affects acid products. *B. stearothermophilus* has caused spoilage of many products, including peas, corn, and asparagus, while *B. coagulans* has been a problem primarily in tomato products. *B. coagulans* has rarely spoiled low-acid products, because of the severe heat process that these products receive. However *B. coagulans* spores are sufficiently heat-stable to survive the milder heat processes used for acid foods (Anon. 1968).

Spores of *B. stearothermophilus* are widely distributed in soil. Sugar and starch can be important sources of contamination. Other ingredients such as vegetables, milk powders and spices may also contribute to contamination. Unlike the thermophilic anaerobes, which will be discussed later, build-up of contamination in the plant can be an important source of flat sour organisms, since they are well adapted to growth in heated equipment such as blanchers, fillers and mixing tanks. *B. coagulans* is found in soil and may be present on tomatoes and other raw materials.

An interesting property of the flat sour bacilli is the tendency of spores that survive a heat process to lose viability if stored at temperatures that are too low to support growth. If canned foods containing flat sour spores are stored for a few weeks at mesophilic growth temperatures, a progressively smaller proportion of cans will spoil on incubation at elevated temperatures. This is not a characteristic of the thermophilic anaerobes (Pearce and Wheaton 1952).

Although thermophilic *Bacillus* species are commonly associated with flat sour spoilage, they are also capable of causing swells in canned foods and similar products. Recent examples of this type of spoilage examined in our laboratory are described in Table 3. No attempt was made to determine the taxonomic position of the isolates.

Several *Bacillus* species, such as *B. subtilis, B. brevis* and *B. licheniformis,* include strains that are termed facultative thermophiles. These are capable of growth at both 30°C and 50°-55°C. These bacilli may swell cans and produce acid in affected products and we have examined a number of cases of spoilage by such organisms, usually caused by underprocessing.

TABLE 3

Microbiological findings in swollen cans spoiled by thermophilic *Bacillus* species

(a) Corned beef

Condition of product: soft-hard swell, sickly odour
Microscopy: 2-20 bacilli/field
pH: 5.7-5.8 (normal = 6.2)
Cultures: 30°C — no growth
55°C — *Bacillus* strains detected using brain heart agar, cooked meat medium, pork infusion agar. 10^2-10^3/g of product.

(b) Peas in sauce

Condition of product: soft swell, sauce liquefied
Microscopy: 5-20 bacilli/field
pH: 4.9-5.0 (normal = 6.1)
Cultures: 30°C — no growth
55°C — *Bacillus* strains detected using brain heart agar, cooked meat medium, pork infusion agar. 10^4-10^5/g of product.

Clostridium species

Thermophilic anaerobes that do not produce H_2S, usually assumed to belong to or be closely related to the species *C. thermosaccharolyticum,* are the most important thermophilic clostridia involved in food spoilage. They are not proteolytic but are vigorously saccharolytic and produce acid and large amounts of gas from many carbohydrates. The products of fermentation include carbon dioxide, hydrogen, acetic and butyric acids and ethanol. *C. thermosaccharolyticum* causes hard swells of spoiled cans, which may burst. The food has a lowered pH and often a butyric odour. Cells of *C. thermosaccharolyticum* are long, slender rods that stain Gram negative, often with a granulated appearance. Spores are terminal and swell the sporangium.

These thermophilic anaerobes are widely distributed in soil and composts. Ingredients found to be a source of spores include vegetables such as dried onion and mushrooms, sugar, starch, tomato paste, cereal products and dried milk. Raw materials are a more likely source of contamination than growth of the organism in the food processing plant.

Spoilage has occurred in a variety of products with pH values greater than 4.7, particularly vegetable products, e.g. beans, mushrooms, asparagus, pumpkin, spaghetti in tomato sauce and soups. There are also some reports of spoilage of fruit products and tomatoes with lower pH values. Although there is evidence that *C. thermosaccharolyticum* can cause spoilage at temperatures as low as 30°C, the presence of viable spores of this species in canned foods is not generally considered to be a problem unless the product is inadequately cooled after processing or stored at elevated temperatures (Ashton 1981).

C. thermosaccharolyticum causes spoilage in Australia, but apparently not frequently in recent years. An incident involving canned mushrooms, investigated at this laboratory illustrates the essential features of spoilage by these organisms (Table 4). After experiencing spoilage of the product, the manufacturer sent samples of unspoiled cans to the laboratory for examination. Cans incubated at 30°C for a month did not swell, while cans incubated at 50°C for a few days swelled, often to such an extent that the seams were distorted or the can burst. The organisms did not grow in cooked

TABLE 4

Microbiological findings in canned mushrooms spoiled by thermophilic clostridia

Condition of product: hard swell, some cans burst; foul odour, brine cloudy
Microscopy: 2-100 bacilli/field
pH: 4.4-5.9 (normal = 6.3)
Cultures: 30°C — no growth
55°C — scanty growth in brain heart broth and liver peptone broth; good growth of slender, spore-forming anaerobic rods in corn liver medium.

meat medium, dextrose tryptone agar, or pork infusion agar. The manufacturer overcame the problem by increasing the severity of the heat process and paying increased attention to cleanliness of the raw materials. Spoilage of canned soy-based infant formula and a canned chicken product by *C. thermosaccharolyticum* have also been investigated by this laboratory.

Thermophiles are particularly likely to undergo autosterilisation, that is, the organism spoils the product then dies, making the precise cause of spoilage difficult to determine. We have investigated other spoilage outbreaks that were probably due to *C. thermosaccharolyticum*, but viable organisms have not been detectable in the product. A notable example was a problem with imported canned asparagus.

There are a number of thermophilic clostridia other than those already discussed. One species, described as *C. thermoaceticum*, has caused flat sour spoilage of canned drinks from hot vending machines in Japan (Nakayama *et al.* 1984). The drinks involved included coffee and a Japanese sweet bean drink. Similar spoilage has been reported in canned vegetables. Isolates have an optimum growth temperature around 60°C and do not grow above 70°C or below 40°C. The minimum pH at which they grow is about 5.5. They ferment several carbohydrates without gas production. Reports of this kind of spoilage have been rare outside Japan.

Desulfotomaculum nigrificans

D. nigrificans, once known as *C. nigrificans*, is an anaerobic, spore-forming, Gram negative rod. It does not ferment carbohydrates. Its most important metabolic activity in food is the reduction of sulphate or other inorganic sulphur compounds to sulphide. Spoilage is characterised by an odour of hydrogen sulphide and greying or blackening of the product and is referred to as sulphide stinker spoilage. There is usually no swelling of the container; the hydrogen sulphide is soluble in the aqueous portion of the pack (Speck 1981).

D. nigrificans has caused spoilage of canned corn, peas, baby clams, and especially mushrooms. It does not tolerate acid conditions, the minimum pH for growth is 5.8-6.2. It is found in soils, composts, manure and waters. Ingredients identified as sources of the organism are sugar, starch, mushrooms and dried milk. *D. nigrificans* has exacting growth requirements, and is said to be the thermophile that least readily becomes established in food processing plants (Speck 1981).

D. nigrificans spores can be extremely heat resistant. Until investigations prompted by outbreaks of sulphide stinker spoilage of canned mushrooms in the USA in the 1970's, it was considered to be less heat resistant than *B. stearothermophilus*, with a D value at 121°C of about 2-3 minutes. With new methods for preparing spore crops and for counting survivors after heat treatment, D values of up to 54.4 minutes were observed at 121°C (Donnelly and Busta 1980).

Spoilage caused by *D. nigrificans* is not common, but when sulphide stinker spoilage does occur it can have a substantial economic impact. This laboratory has investigated only one case of spoilage caused by *D. nigrificans*, in Australian canned mushrooms that have been incubated at elevated temperatures.

TABLE 5

Media for cultivation of thermophiles

Thermophile group	Medium[1]	Reference[2]
Flat sours (*B. stearothermophilus*)	Dextrose tryptone agar	1
Aciduric flat sours (*B. coagulans*)	Thermoacidurans agar	1
Anaerobes not producing H_2S (*C. thermosaccharolyticum*)	Liver broth	1
	Corn liver medium	2
	PE-2 medium	3
Anaerobes producing H_2S (*D. nigrificans*)	Iron sulphite agar	1
	Fluid thioglycollate medium + iron	4

[1] Incubation should be at 55°C, under aerobic or anaerobic conditions as appropriate

[2] References: 1, available commercially; 2, Anon. (1968); 3, Ashton (1981); 4, Speck (1981)

Detection of thermophiles

The media used most commonly in the food industry for the detection of thermophiles are detailed in Table 5. The flat sour bacilli are not very fastidious in their growth requirements. However, procedures for enumerating these bacilli should be strictly standardised. Special precautions, discussed by Lovelock (1980), must be taken with the heat process used to inactivate vegetative cells and heat labile spores when enumerating spores of thermophiles. The media commonly used for cultivation of *D. nigrificans* are not highly regarded. Sporulation of the anaerobes listed in Table 5 may be difficult to induce. Media containing carbon sources that reduce the growth rate (e.g. corn starch) support good sporulation of *C. thermosaccharolyticum*, while readily utilised carbohydrates like glucose repress sporulation (Hsu and Ordal 1969).

TABLE 6

Suggested standards for counts of thermophile spores in sugar and starch used in low-acid canned foods[1]

	Maximum	Average
Flat sours	75/10 g	>50/10 g
Total aerobes	150/10 g	>125/10 g
Anaerobes not producing H_2S	3/5 samples positive[2] 4/6 tubes positive/sample	
Anaerobes producing H_2S	2/5 samples positive[2] 5/10 g in any sample	

[1] 5 samples tested per batch. Analyses performed as specified by Anon. (1968)

[2] in 4 g

Control of thermophilic spoilage

Control of initial contamination

Given the heat resistance of spores of thermophilic bacteria, control of contamination of the product before heat processing is essential. Ten or twenty spores per can may be sufficient to cause spoilage. High risk ingredients such as sugar, starch, and meat fractions can be monitored to ensure that they meet appropriate microbiological specifications. Some relevant specifications are summarised in Table 6 (Anon. 1968). Many ingredients cannot be subjected to microbiological control, but attention can be given to procedures that reduce contamination, for example washing of vegetables. Some raw materials can be pre-treated to reduce contamination, for example, HTST treatment is sometimes used to reduce *B. coagulans* counts in tomato juice.

Good hygiene and sanitation and careful design of equipment in the processing plant are important in preventing growth of thermophiles in the plant and increased contamination of the product. Problems may also be experienced if hot-filled products are held for long periods at temperatures in the thermophilic growth range because of production problems or poor planning.

Process control

Good control of heat processes is important for many reasons, including prevention of thermophilic spoilage.

Prevention of growth in finished products

Prevention of growth of thermophiles after processing is important, since thermophile spores are likely to survive some commonly-used heat processes. Food processors usually minimise the heat processes they use in order to avoid undesirable organoleptic changes caused by heat. Therefore small numbers of viable thermophile spores are often tolerated in products that will not be subjected to high storage temperatures. The thermophiles are not a hazard to the health of consumers and the presence of viable thermophiles does not necessarily mean that a product is not commercially sterile.

The most important safeguard against the growth of thermophiles is effective cooling after heat processing, to ensure that the product does not spend an excessive time at elevated temperatures. Containers should be cooled to at least 35°-40°C. This is particularly important for large cans and packs that lose heat by conduction, e.g. cream style corn. Cans that are close stacked while too hot may take weeks to cool. If canned products must be exposed to high temperatures, e.g. products destined for the tropics or hot-vending machines, extra care is necessary with the other precautions.

Control of the composition of the product, especially pH, may be important in preventing growth of thermophiles. For example, pH control can help to prevent *B. coagulans* from spoiling tomato products, which are sometimes acidified to pH 4.1 for this purpose. Anti-bacterial agents may help to control thermophilic spoilage. The antibiotic nisin, which inhibits spore outgrowth, is approved for use in Australia in certain heat processed tomato products and canned soups. Broader use of nisin and other antibiotics has been suggested on many occasions. Sucrose esters of fatty acids were used to control the clostridial spoilage of hot-vended drinks discussed above. Australian food processors must, of course, seek permission and establish a technological need before using such additives for new applications.

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