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Precooling and Container Shipping of Citrus Fruits

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The quality of citrus fruits at the point of sale is largely dependent on the treatment given to them and the environmental conditions experienced since harvesting. Control of the environment is becoming an important part of marketing technology and cooling is the major factor in this control. This paper deals with methods of precooling, particularly the potential of evaporative cooling, and then considers the application of precooling to citrus fruits in Australia. Finally, there is some reference to container shipping of citrus.

Precooling

Effects on the Fruit

Every fruit when it is picked has a characteristic, fixed life potential which is determined by its natural rate of respiration, whether slow or fast, and by its metabolic reserves. This life potential is a direct expression of keeping quality—a high life potential means slow aging and good basic keeping quality. However, storage life can be terminated by any one of the following:

- Aging and over-ripeness
- Rotting
- Some form of physiological injury such as scald or breakdown
- Wilting

Wilting is controlled by maintaining a high humidity in the store. Physiological injury is usually due to an unfavourable environment such as too low a temperature, too much carbon dioxide, or too high a humidity. Rotting is determined by the amount of infection, either in the orchard or during handling, by the susceptibility of the fruit, and by the temperature. The rate of ripening, the rate at which the initial life potential is expended, and the rate of development of fungal wastage are directly dependent on temperature.

It therefore follows that, with very few exceptions, the sooner fruit is brought to its best storage temperature after picking, the longer will it keep. It also follows that the gain from quick cooling will be correspondingly greater for the more perishable, faster respiring kinds of fruit.

Precooling of more perishable produce before transport to market can considerably improve its condition and quality at the point of sale and the practice is well established. With soft fruits precooling is mainly to slow down the rate of ripening, but with citrus it is mainly of value to minimize shrinkage and softening of the fruit and so to maintain its freshness and to avoid the development of off-flavours which occurs at high temperatures.

Besides increasing storage life, fast cooling reduces loss of moisture from the produce and therefore reduces shrivelling. Other things being equal, moisture loss is proportional to the difference in water-vapour pressure between the product and the surrounding air and the time for which this difference exists. The equilibrium vapour pressure of oranges and other fruits is close to the vapour pressure of water and, as it is approximately constant, the rate of weight loss from fruit is directly proportional to the (water) vapour pressure deficit of the air which, in turn, is a function of its temperature and humidity (Fig. 1). Fast cooling not only quickly reduces the difference in water-vapour pressure but also reduces the time factor. If high humidities are maintained, as in evaporative cooling, weight losses during cooling can be kept low. With both slow cooling and low humidity, weight losses can be considerable and wilting serious.

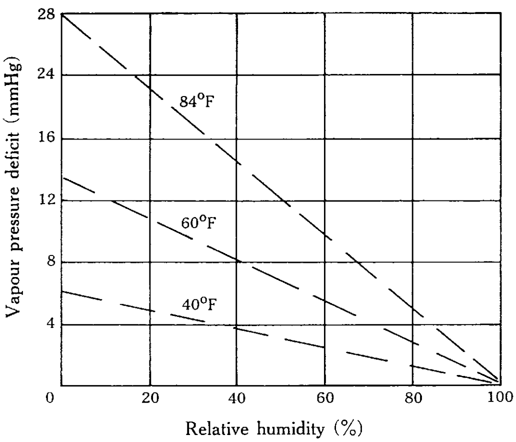

Fig. 1.—Relationship of temperature and relative humidity to vapour pressure deficit.

High air velocities, which increase the rate of cooling, increase the rate of water loss but, because the more rapid reduction in temperature speeds up cooling, the use of high air velocities actually reduces shrinkage of the fruit.

Cooling Rate

The rate of cooling is conveniently expressed as half-cooling time, or Z value. In practice, first half-cooling time is generally used. As this is independent of air and produce temperature and is generally nearly constant during the whole of cooling for a particular pack and package, stowage pattern, and refrigeration system, it makes possible a comparison of the effects of these and other factors independent of temperature. For practical purposes the half-cooling time is the time taken for the temperature of the fruit to be reduced to half the initial difference in temperature between the warm product and the cooling air. Thus, for fruit at a temperature of 70°F being cooled with air at 30°F the half-cooling time would be the time for the fruit to cool by 20°F, $(70-30)/2$, i.e. to 50°F. Further cooling by 10°F, $(50-30)/2$, to 40°F would take the same time and further cooling by 5°F, $(40-30)/2$, to 35°F would still take the same time. It will therefore take as long to cool from 34 to 32°F as it did from 70 to 50°F, provided always that the refrigeration capacity is adequate to cope with the initial heavy sensible heat load.

Quick cooling is a relative term but might be used to describe cooling that results in the temperature of the fruit being down to 40°F in 48 hr or less. This normally requires half-cooling times of 20 hr or less, i.e. initial cooling by at least 1 degF per hour and only a few hours' delay between picking and cooling. Although initial cooling rates at 2–3 degF or even 4 degF per hour are possible, experience has shown that an initial rate of 1 degF per hour in the centre fruit in the centre of the pack is both satisfactory and practicable for packed fruit. However, even this rate cannot be obtained consistently without proper care and attention.

Methods

Cooling can be accomplished by transferring the heat from the produce to a stream of cold air, as in normal cool storage and in various systems of air cooling, or to water (hydrocooling), or principally by evaporation of water as in vacuum cooling or evaporating added water from the surface of the produce.

In ordinary room cooling the heat is carried away by slowly moving air mainly from the surfaces of the packages. Therefore the limiting factors in cooling are package size, assuming heat transfer within the package is almost entirely by conduction, and stowage patterns. If a significant proportion of the air is forced through the containers and over the produce itself, this considerably speeds heat transfer and gives quicker cooling.

Because water has a much greater heat capacity than air, hydrocooling, in which the produce is brought into direct contact with moving cold water, is much faster than air cooling methods.

Produce with a high surface/volume ratio can be cooled extremely fast by vacuum cooling and most lettuce and large quantities of other leafy vegetables are cooled this way in the U.S.A.

Finally, produce may be cooled quickly by body icing or top icing, in which crushed ice is mixed with or blown over the load. Since the transfer of heat is due mostly to the water from the melted ice, this method is in effect a form of hydrocooling. Direct icing at the beginning of the journey used to be the common method of cooling lettuce for shipment in the United States.

In North America liquid nitrogen is now cheap enough to be used for refrigeration and cold air cooled by expanding nitrogen gas from cylinders into the space is being used for precooling and cooling in truck transport.

Table 1 shows the different speeds of cooling apples obtainable by the various methods. Rates for citrus fruits would be similar.

Table 1
Comparative Cooling Speeds for Apples in Bushel Boxes

Cooling method	*Z* (hr) Fruit loose in box	Fruit wrapped and packed
Conventional cool room: *c.* 30 changes/hr, or convective circulation from ceiling coils, open stack	12	22
Large cool room: vertical air, 150 changes/hr, open stack	8–10	15–22
Tunnel: air velocity 500–1000 ft/min, forced air or pressure cooling	3–4	*c.* 14
High-speed jet cooling: air velocity *c.* 2500 ft/min over fruit	$\frac{3}{4}$	
Hydrocooling (loose fruit)	$\frac{1}{4}$–$\frac{1}{3}$	

Value of *Z* for single fruit: air *c.* 100 ft/min, $1\frac{1}{4}$ hr; air *c.* 1000 ft/min, $\frac{1}{2}$ hr.

Cooling with Cold Air

In a cool store, whether the air is cooled by mechanical refrigeration or by use of an evaporative cooler, it is only moving air which carries the heat away from the fruit, and satisfactory cooling depends on adequate movement of cold air over the fruit if it is exposed or over each individual box, carton, or other package if it is not. Therefore the speed of cooling depends on the temperature of the air, the speed of the air, and the degree of exposure of the fruit or the package.

The effects of the package and of stacking on cooling rates of apples are summarized in Table 2. These are only approximate values as actual cooling rates will depend very much on the particular conditions in each instance.

Table 2
Expected Half-cooling Times of Centre Fruit for Various Packages

Package	Half-cooling time (hr) Freely exposed	Open stow*	Tight stow*
Standard apple box, loose fruit, unlidded	5–8	15–20	40–50
Standard apple box, wrapped and packed	20–25	30–40	40–50
Cell-pack carton	18–25	30–40	80–100
Tray-pack carton	20–25	40–45	80–100
Export apple bin, no floor vents	25–35	40–50	50–60
Export apple bin, 8% floor vented	20–25	30–40	35–50
4 × 4 × 2 ft open-top bulk bin			
No floor vents	15–20		
5% Floor vented	10–12		
10% Floor vented	5		

* On 44-case pallets.

Precooling before Packing

It is generally best to precool before packing. The reasons for this are:

- The unavoidable weight loss of half a per cent or so during cooling then does not slacken the pack and reduce net weights;
- Cooling of loose fruit is much quicker than cooling of packed fruit in boxes or cartons, twice as fast loose in boxes, and three or four times as fast in floor-vented bins.

A disadvantage of grading and packing cold fruit is that it may become wet by condensation of atmospheric moisture on it resulting in the fruit picking up dust which becomes unsightly when the fruit later dries.

Hydrocooling

Hydrocooling is cooling under drenching sprays of cold water or by immersion in a tank of cold water. It is competitive in cost with other methods of fast cooling and has the considerable advantage that no moisture is lost from the produce. Hydrocooling has been widely used in the U.S.A. for a variety of perishable vegetables and for stone fruits. The method could be worth while with these fruits in Australia, especially in hotter climates, both for immediate marketing and for storage.

Some preliminary tests of hydrocooling peaches were carried out at Bathurst, N.S.W., early in 1964, using a small batch-type flooding spray hydrocooler. Half-cooling times for peaches loose in two layers in vented half-bushel boxes varied from 8 to 15 min for fruit ranging in size from $2\frac{3}{8}$ to $3\frac{1}{8}$ in. in diameter at a flow rate of 6–7 gal/min/ft^2. These rates agree with those reported by American workers. Using melting ice in the tank it was not possible to have the water at the fruit colder than $33\frac{1}{2}$–34°F. These tests showed that hydrocooling could cool peaches from 80 to 40°F in 30 min and from 80 to 36°F in about 40 min. Similar rates could be expected with citrus.

Hydrocooling of citrus fruits has been extensively studied in the U.S.A. by Grierson and others (Eaks 1956; Grierson and Hayward 1958; Hayward 1962). It has proved unsatisfactory because of increased decay, particularly after the fruit later warmed up, a degree of physiological damage, mainly by uptake of water into its tissues by warm fruit in cold water, and the difficulty of developing a hydrocooling system that could be integrated into the packing line.

Forced-air Cooling

Recently (Soule, Yost, and Bennett 1969; Grierson, Bennett, and Bowman 1970) there have been strong attempts in Florida to develop a system of fast cooling with very cold air which could be practicable in packing houses. This followed the earlier work on forced-air cooling of fruit by Guillou (1960) in California.

Using approach velocities of 250–300 ft/min and air at temperatures of the order of 20°F, fruit in open, wire-bound boxes was cooled from 85 to about 50°F in half an hour. Closing the packages halved the rate and oranges in net prepacks or film shrink-packs cooled as fast as the unwrapped fruit in open cartons. The fruit was not injured provided that its surface temperature did not fall below 28°F (its freezing point) and weight losses during cooling were less than 1%.

Grierson, Bennett, and Bowman (1970) concluded that the concept of multi-stage forced-air cooling has commercial potential for packing house 'in-line' precooling of citrus fruit.

Evaporative Cooling

In inland areas, evaporative coolers have a valuable place in citrus packing houses and could also be usefully adapted to road transport vehicles. In the packing house fruit could be cooled on arrival and held under conditions of low evaporation, and packed fruit awaiting despatch could be similarly held. Evaporative cooling is basically a simple process and simple installations which could be constructed by anyone interested would be useful on the orchard for holding fruit. In principle, evaporative cooling occurs when air that is not already saturated with water vapour is blown across any wet surface. Two evaporative cooling methods in particular have aroused considerable interest in the Australian fruit industry and will now be outlined.

In one of these methods, one or more walls of the storage room are made into a large evaporating surface with a coarse, porous filling material, such as washed and graded coke, which is packed between 4-inch studs and held in place by wire netting, the whole being kept moist with water. Thus atmospheric air drawn from outside with a cheap forced-air circulation system is cooled and humidified while passing through these moisture-laden walls and, in turn, cools the fruit in the room.

Evaporative cooling of air may also be carried out in special equipment such as a packed cooling tower. This is a tower that has been packed with a filling material, this now constituting a 'packed bed' through which atmospheric air and water are caused to flow in countercurrent fashion. In order to serve as an efficient air conditioner, the packed bed should consist of a material with a large specific surface area (i.e. a large area per unit volume of bed), and to meet this requirement a number of manufactured ceramic products of uniform size and shape are commercially available.

Evaporative cooling is widely used for comfort cooling of living and working spaces in hot, dry climates and it could have a considerable potential for the precooling of fruit in the Lower Murray and areas with similar climate. Climatic averages for Berri over a 25-year period are given by the Commonwealth Meteorological Bureau in Table 3.

Theoretically, the lowest temperature that can be reached when cooling is by evaporation

Table 3
Average Daily Readings over 25 years at Berri, S.A.

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Mean max. temp. (°F)	80·7	85·8	87·7	86·3	82·3	72·5
Mean min. temp. (°F)	54·0	57·6	59·1	58·9	56·0	50·0
Av. index mean relative humidity (%)	46	43	43	47	51	61
Av. temp. (°F)	67·4	71·7	73·4	72·6	69·1	61·2
Av. wet bulb (calc.*)	55·0	58·5	59·0	60·0	58·0	54·0

*E.g. in January with dry bulb 88°F, wet bulb = *c*.67°F.

of water is the wet-bulb temperature which, on the above figures, would be close to 60°F at Berri from December to March. In practice it is not usually economic to work on more than 80% saturation of the air going through an evaporative cooler. This means that it would be practicable, on the Berri figures, to cool the air to 65°F. The temperatures theoretically obtainable from a single-stage evaporative cooler are shown in Table 4.

The latent heat of vaporization of water is about 970 Btu/lb, so that if there were no losses the evaporation of 1 lb of water could cool about 900 lb of fruit by 1 degF or 45 lb of fruit, initially at 80°F or higher, by 20 degF.

Thus, allowing for normal operational losses, it could be expected that the cooling of fruit through 20 degF would require the evaporation of about 10 gal water per ton of fruit cooled.

With air at 65°F it should be quite practicable to cool unwrapped fruit in open-top bottom-slatted field boxes, slatted bulk bins, or in cleated, open-top ½-bus. or ⅔-bus. boxes from 80°F to 70°F in 20 hr. To cool fruit in cartons by the same amount would probably take 2–3 days.

All the packing houses and some individual growers along the Murray have tunnel dehydrators which could probably be converted at little expense for use as evaporative coolers during the summer months. With continuous running of the evaporator and fan, fruit could be held in the tunnel at a temperature of about 70 to 75°F with high R.H. and little shrinkage. Existing buildings could be cooled evaporatively and used as fruit coolers, but with reduced efficiency unless insulated.

An important advantage of evaporative cooling is that the humidity of the air leaving the cooler is nearly saturated and the R.H. in the storage space can readily be kept above 80% so that weight loss and shrinkage of the produce during cooling and holding can be kept low. Apart from any gain by reducing fruit temperatures the application of evaporative cooling to citrus would probably be justified on control of shrinkage alone.

We have not yet been able to evaluate the packed-wall cooling method, but we have undertaken a considerable number of performance tests on the first packed cooling tower put in operation in a Murray River

Table 4
Air Temperatures Obtainable by Single-stage Evaporative Cooling
(At atmospheric pressure 30 in., altitude 0–1000 ft)

Water vapour per lb of dry air (grains)	Dew point (°F)	Dry bulb (°F)	Relative humidity (%)	Wet bulb (°F)	Temp. of air *ex* cooler (80% saturation) (°F)
30	35	100	11	64	71½
		90	15	60	66
		80	20	56½	61
		70	28	52½	56
		60	40	48	51
40	42½	100	15	66	73
		90	19	62½	68
		80	26	59	63
		70	37	55	58
		60	53	51	53
50	48	100	17	68	74½
		90	24	64½	69½
		80	33	61	65
		70	46	57	59½
		60	66	54	55½
60	53	100	21	70	76
		90	29	66½	71½
		80	40	63½	67
		70	55	60	62
		60	78	56	57½
70	57	100	25	71½	77½
		90	34	68½	73
		80	46	65½	68½
		70	64	62	64
		60	90	58½	59

Table 5
Citrus Fruit Temperature Survey—Sunraysia 1970/71
Packing House A. Monthly mean temperatures and ranges in temperature (°F)

Month	No. of temp. samples	Av. top of bin as received	Range, top of bin	Av. 1 ft down in bin as received	Range, 1 ft down in bin	Av. at packing (2 fruit sampled)	Range, at packing	Av. air in shed	Range, air in shed
viii.70	20	54	44–66	53	40–56	57	44–63	54	43–62
ix.70	36	58	46–76	57	46–80	57	44–78	55	42–74
x.70	35	65	50–80	64	50–81	66	52–81	65	52–80
xi.70	36	70	54–91	68	53–89	70	51–86	71	54–91
xii.70	23	74	59–94	72	59–87	73	57–90	75	60–98
ii.71	20	79	72–86	78	70–84	81	72–96	82	72–98

packing house. The tests showed that when the external air had a temperature of 102°F and a relative humidity of 6·5% the cooling tower was capable of delivering air to the cool room with a temperature of 64°F and a relative humidity of 95%; the temperature of the cool room was then 78°F, that is 24 degF lower than the outside air.

Several storage experiments have since been carried out in this cool room. On the occasion just cited the cool room contained an experimental load of oranges; the temperature of these, after they had been stored thus for 16 hr, had been lowered 20 to 25 degF. On another occasion, when weight losses were studied, it was found that oranges stored in a non-conditioned room lost nearly twice as much weight as oranges stored in the room served by the evaporative cooling tower.

It has been stated that oranges cooled and held in this room and cooled and humidified by the specially designed evaporative cooler arrived on the Sydney market during the summer in a fresher and more attractive condition than formerly.

Need for Precooling in Inland Areas

To develop a basis for deciding when and where precooling of citrus is necessary a survey of fruit temperatures was carried out during the spring and summer of 1970–71 in packing houses in the Sunraysia area, with the cooperation of packing house staff and Australian Paper Manufacturers Ltd. The data from a packing house in Mildura are typical and are summarized in Tables 5 and 6. From August 1970 to February 1971, temperatures were measured at 8.00 a.m. and 4.00 p.m. as follows:

(*a*) top fruit in bins as received

(*b*) fruit 1 ft down in the bins as received

(*c*) fruit as soon as packed

(*d*) air temperature in the shed

As would be expected, there was an increase in all temperatures during the period; average 8.00 a.m. air temperatures rose from 49°F in August to 76°F in February and 8.00 a.m. packed fruit temperatures from 52°F to 77°F. The average 4.00 p.m. temperatures were considerably higher, air tempera-

Table 6
Citrus Fruit Temperature Survey—Sunraysia 1970/71
Packing House A. Mean temperature (°F) at 8 a.m. and 4 p.m.

Date	No. of days		Av. top of bin as received		Av. 1 ft down in bin as received		Av. at packing		Air in shed	
	a.m.	p.m.	8 a.m.	4 p.m.	8 a.m.	4 p.m.	8 a.m.	4 p.m.	8 a.m.	4 p.m.
18–31.viii.70	10	10	50·5	59	51	54·5	52·5	61·5	49	59·5
1–30. ix. 70	18	14	53·5	63	54·5	60·5	52	63·5	49·5	62
1–30. x. 70	20	15	60·5	72	61·5	68·5	58·5	71	58·5	72·5
2–30. xi. 70	19	17	65	75	65	71	62·5	76	64	78
1–21. xii.70	15	8	71	80	69	76	69	79·5	70	84
15–26. ii. 71	10	10	77	82	75	81	77	85	76	87·5

tures rose from 59°F in August to 87°F in February and packed fruit temperatures from 61 to 85°F. Maxima on any one day were well above these average figures, maximum packed fruit temperatures were around 80°F in September and October, 86°F in November, 90°F in December, and as high as 96°F in February.

To check on cooling rates of oranges in wire-bound boxes during transport to Britain in I.S.O. insulated containers an experimental shipment of sixteen containers of Valencia oranges so packed was carried out by Overseas Containers Australia Pty. Ltd. in 1970. Mean fruit temperatures at the time of loading into the containers in South Australian packing houses on September 9–11, 1970, ranged from 54 to 69°F per container; the lower values were caused by a cool change. During the 3-day rail journey fruit temperatures rose by only 1–1·5 degF.

In mid September and at the end of September 1969, fruit temperatures at the loading of I.S.O. insulated containers in South Australian citrus packing houses were about 58°F and from 53 to 63°F respectively, during relatively cool weather. In a special test it was shown (Tugwell *et al.*, unpublished data) that there was no significant change in these temperatures during rail journeys to Melbourne of 50 and 70 hr duration.

There are further data from South Australia on pulp temperatures of oranges at the time of loading into containers for export. From June 7 to July 15, 1970, out of 83 containers checked, 5 were loaded with fruit at 60 to 62°F, 17 with fruit at 57 to 59°F, and the remainder with cooler fruit. The pulp temperatures at loading of an experimental shipment of Navel oranges late in July ranged from 52 to 71°F. However, when Navels are exported during June and early July fruit temperatures at loading seem to be about 55°F. In mid September in 1970 the average temperature of Valencias when loaded into containers in South Australia for export was reported to be 63°F.

Oranges lose considerable weight after picking if they stand in bins for a few days awaiting processing. At the end of October, Valencias in bins in a shed in Mildura lost about 1% per day for top fruit and ¾% per day for fruit one foot down from the top, and rates for small fruit were higher (Table 7). In a similar test at the Mildura Research Station weight losses were less, but still considerable (Table 8). Trout, Tindale, and Huelin (1938) reported daily weight losses from Navel oranges after harvest of 1·5% at 84°F and 50% R.H. and 2·4% at 90°F and 50% R.H. Under summer conditions in inland areas daily weight losses in excess of 1% can be expected from unprotected fruit in bins.

Table 7

Percentage Weight Loss from Valencia Oranges in Bins in Packing House, Mildura, 21 October to 1 November 1970 (10 fruit units)

Fruit size (in.)		3⅛–3¼	3	2¾	2½	2¼	2–2⅛
Top of	Bin 1	8·1	7·8	8·0	8·0	10·0	11·7
bin	Bin 2	7·3	9·0	7·9	8·3	9·2	10·4
1 Ft	Bin 1	5·0	5·0	6·1	6·9	7·7	10·4
down	Bin 2	5·8	5·0	6·0	5·6	7·0	8·4

Mean temp. (°F): *c.* 62
Mean R.H. (%): *c.* 47

Table 8

Percentage Weight Loss from Valencia Oranges in Bins at Research Station, Mildura, over 11½ days, late October 1970 (10 fruit units)

Fruit size (in.)		3⅛–3¼	3	2¾	2½	2¼	2–2⅛
Top of	Bin 1	9·0	7·8	8·2	8·1	10·0	11·8
bin	Bin 2	7·3	8·8	7·7	8·3	9·3	10·4
1 Ft	Bin 1	5·5	5·2	6·1	6·9	7·8	10·5
down	Bin 2	5·4	4·9	6·0	5·6	7·0	8·4

Air temp. (°F): max. 70–86, min. 48–59
Fruit temp. (°F): 62–66
Temp. (°F) of fruit on arrival at shed after picking and bins standing in open for 3 hr awaiting carrier:

Top fruit	89·5	92	90
1 Ft down	63	63	63
Shade air	70		

Wells (1962) studied the effects of relative humidity and vapour pressure deficit on the rates of weight loss from different fruits in storage. He found, as expected, that the rates of weight loss for a particular fruit varied inversely with the relative humidity and directly with the vapour pressure deficit. However, there was a direct effect of temperature. At a given vapour pressure deficit weight loss was higher at higher temperatures, for example, 15–25% higher at 60°F than at 40°F for oranges. This finding further stresses the importance of low temperatures for low weight losses.

While the recommended fungicide treatments will control green and blue moulds, even under warm conditions, it is clear that exposure of citrus fruits to higher temperatures and lower humidities must be avoided if fresh fruit is to be placed on even Australian markets. If early to mid-season Navel oranges are treated, packed, and despatched promptly after harvest, precooling need not be essential for export. However, precooling is desirable for all except very early Valencias and essential for them during the summer.

As control of shrinkage is the main requirement, wide use could be made of evaporative cooling at relatively low cost to protect fruit, both in bins and after packing. With an efficient evaporative cooling installation, fruit temperatures of the order of 60°F could be maintained during October and November, and 65–70°F during the summer. At the same time it should be possible to maintain relative humidities of the order of 80% in an evaporatively cooled room. From Figure 1 it can be seen that, under these conditions, the vapour pressure deficit would be about 4 mmHg compared with four times that amount, or more, without such cooling, and weight loss and shrinkage from the fruit, correspondingly, reduced to one-quarter.

On a much simpler scale, keeping the fruit wet while it is being held in bins in the shed and providing good air movement over it is well worth while to cool it and reduce loss in weight from it. To control mould it is recommended that on arrival, the bins of fruit be either dipped in or flood-sprayed with water containing TBZ or benomyl.

Full use of evaporative cooling before and after packing should satisfactorily cool and protect Valencias exported during September and early October and enable the fruit to be loaded at temperatures not exceeding 60°F. Later in the season, export fruit could also be mechanically refrigerated after packing to enable it to be loaded at a temperature of not more than 50°F. The lower temperature is suggested as later fruit ages sooner after harvest and is more difficult to keep fresh.

Container Shipping

An experimental shipment to Britain in 1970 indicated satisfactory rates of cooling of oranges in 1-bushel wire-bound boxes carried in containers and stowed with or without vertical dunnage. However, it appeared that fruit loaded cooler was somewhat fresher at discharge than fruit loaded warmer.

Oranges in telescopic cartons are more difficult to cool than oranges in unlined, wire-bound boxes. The stowage and cooling of citrus in boxes and cartons during transport have been extensively studied in the U.S.A. Winston, Cubbedge, and Kaufman (1959) reported that in rail shipments from Florida of oranges loaded warm, vented cartons loaded in a space-bonded block pattern (1032 cartons/car) cooled at about the same rate as wire-bound boxes loaded in a layer offset pattern (1056/car).

In studies of rail shipments of cartons of oranges and lemons from California to New York, Atrops and Redit (1962) found that lemons cooled faster in vented than in unvented cartons and oranges in vented cartons loaded in a space-bonded block pattern cooled faster and more uniformly than those loaded in the usual bonded chimney pattern. The former stow exposed much more of the carton surfaces to the cooling air in end-bunker refrigerator cars equipped with fans. In a smaller trial shipment in I.S.O. containers from Melbourne to Britain in 1969, unwrapped Valencia oranges in cartons stowed with vertical laths every second row carried as well as wrapped fruit in wire-bound boxes block-stowed.

Experience in Australia and overseas suggests that Navel oranges and early Valencia oranges, whether packed in boxes or in cartons, shipped overseas in containers need not be specially precooled provided that (i) care is taken to avoid loading warm fruit and (ii) refrigeration of the container commences within three days of loading the container with fruit. While it should not be difficult to have the temperature at loading into the container of most Navels below 55°F and most Valencias during September below 60°F, maximum acceptable pulp temperatures of 60°F for Navels until mid July and 65°F for Valencias until the end of October are recommended for all shipments involving more than three weeks in the container or in the ship. Export of Navels involving such voyages should not be permitted after mid July.

These conditions should, on the data available, be readily met by packing houses. If the fruit is also harvested in a firm fresh condition, promptly processed and packed, and then promptly loaded and despatched, it should arrive overseas in good fresh condition.

Later in the season the permitted maximum temperatures for Valencias should be reduced as the vitality of the fruit diminishes and the weather becomes warmer.

As the survey during the spring and summer of 1970/71 showed, fruit temperatures at packing could be well above 70°F in September and over 90°F in the summer. Such temperatures would severely prejudice the out-turn condition of the fruit. The suggested maximum acceptable loading temperature for Valencias of 65°F would be obtainable during September and October by use of only evaporative coolers whenever cooling is required. However, the citrus industry and the Department of Primary Industry should seriously consider the advantages of lower temperatures, following the lead of other countries; reducing the maximum permitted temperature to 50°F from November 1 on would be of considerable benefit to the fruit. This would require mechanical refrigeration which, it is felt, the industry cannot successfully continue to do without. If facilities for mechanical refrigeration were provided they could be used for Navels with advantage to reduce fruit temperatures at loading to 50°F.

It would be desirable for Ellendale mandarins to be not warmer than 55°F at the time of loading. Lemons and grapefruit, being carried at 50°F, should not need special precooling but, as always, the fruit should at all times be kept as cool as possible.

Those who do more than the minimum precooling and who protect their fruit from water loss will be rewarded by having fresher and more attractive fruit on the increasingly competitive markets. This care is particularly important to avoid rind staining of later Navels and stem-end browning, or aging, of later Valencias. Evaporative coolers are relatively inexpensive to install and are cheap to operate; their regular and systematic use would be of distinct benefit in improving the condition of fruit marketed in Australia, particularly during the summer months.

The above suggested temperatures are compromises and are intended to be a basis for discussion within the industry and within the Departments concerned.

Stowage

Wire-bound boxes of citrus, if precooled as above, can be block-stowed in containers, provided that an air plenum of 2–3 in. is left between the load and the doors and one of at least 2 in. between the load and the roof. Cartons should be vented (according to the S.A.A. code soon to be published) and stowed with vertical laths every second row and air plena as above. To ensure continuous air paths the laths should be lengths of $1\frac{1}{4}\times\frac{1}{2}$ in. timber or their equivalent. It is suggested that mandarins in cartons should be stowed with one side or two ends of every package exposed to dunnaged air paths to ensure good cooling and even temperatures.

Carriage Temperatures and Voyage Lengths

To enable very early poorly coloured Navels to colour and sweeten and early Valencias to sweeten during the voyage it is suggested that Navels shipped before June 7 and Valencias shipped before mid September be carried at 50°F by the container service or in similarly fast ships or for short voyages to nearer ports. Later in the season carriage temperatures for oranges should revert to the normal 41°F. After initial cooling, when they may be several degrees lower, air delivery temperatures should be 1 degF lower.

Lemons and grapefruit should be carried at a temperature of 50°F.

Ellendale mandarins should be carried at 45°F except that those from Queensland exported after June 30 should be carried at 41°F. If oranges or mandarins and lemons or grapefruit have to be carried together in the one space or container, the temperature should be 45°F.

Voyage lengths, by which is meant the total times in the container or ship's hold, of more than six weeks for Navel oranges and Ellendale mandarins and more than eight weeks for Valencia oranges, lemons, and grapefruit are risky and should be avoided.

Conventional Ships

The rates of cooling in containers are at least equal to, and in many instances faster than those in conventional ships. In addition, the container service is often faster. Therefore the same requirements for maximum fruit temperatures at loading should apply to consignments carried in conventional ships wherever refrigerated carriage is required, irrespective of the length of the voyage.

Acknowledgments

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Crustacean Processing and Quality

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This article is based on an address given to the Federal Conference of the Australian Institute of Refrigeration, Air Conditioning and Heating (Inc.), Western Australian Division, Perth, May 3–7, 1971.

Australia's fishing industry is not large by world standards; fish, mollusc, and crustacean catches combined total 100 thousand metric tons compared with a world catch of 63 million tons (Anon. 1971).

Fishing effort is concentrated on the coastal and continental shelf and crustaceans represent a high and increasing proportion of all fish species caught. The total value of fin fish caught in Australia was $15 million in 1970 for 55,000 tons and the value of the crustacean catch was $34 million for 25,000 tons. Crustaceans, including rock lobster, prawns, and a small quantity of crab, are mainly exported in the frozen form to the U.S.A. and Japan; they represent about 2·5% of the world crustacean catch. In 1969 $22 million was gained by the export of frozen rock lobster tails and $12 million from frozen headless prawns. Other products of coastal fishing exported during 1969 were valued at $3·1 million—whole rock lobsters $1·28 million and canned abalone $2·08 million.

Several joint-venture enterprises were established to exploit the extensive prawn resources in northern Australian waters and in seas adjoining Papua New Guinea, but individual fishermen still account for by far the largest proportion of the prawn catch.

Eating Quality of Crustacea

Rock lobsters and prawns have very good eating qualities. The flesh is not tough, certainly not in the toughness range of land animals, and it is seldom soft except in animals that have recently moulted. The flesh is homogeneous and free from arteries or veins. An occasional flavour defect, the 'iodoform' taint, may be present naturally in the flesh of some prawns, but it is not regarded as serious unless it is very strong. Processing may produce unfavourable changes in texture

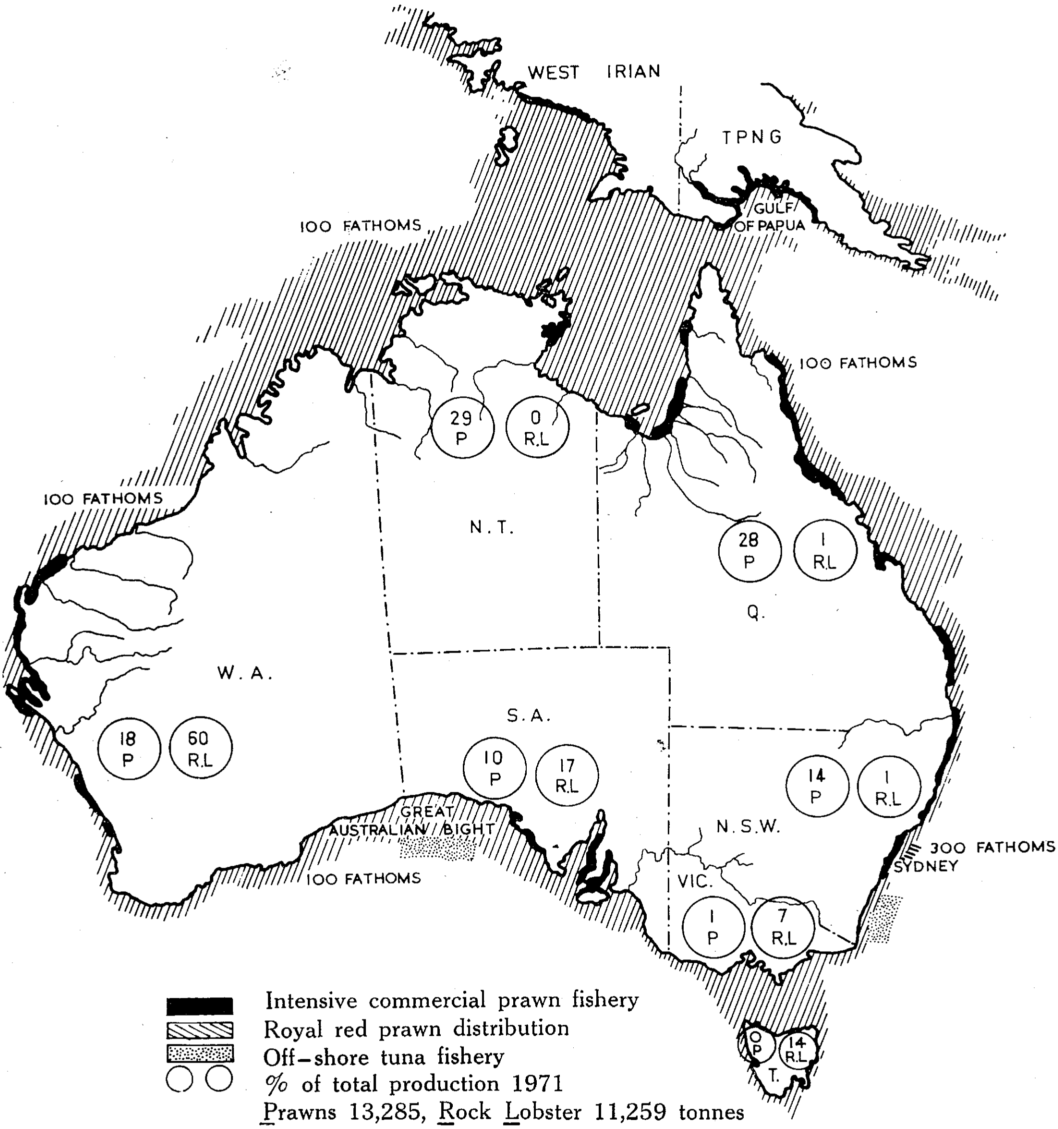

Fig. 1.—Continental shelf and prawn-producing areas, 1971.

or flavour but these can be avoided by changes in processing and/or handling methods, for example, prawns may contain excessive salt and become tough in texture by over-exposure to saline solutions, and colour changes, e.g. blackening or black spot, may occur in prawns kept in air for too long at too high a temperature.

Crustaceans possess qualities that are highly regarded by nutritionists. Lobsters contain appreciable quantities of the natural anti-oxidant α-tocopherol and have very little fat compared with land animals. Probably the most favourable characteristic is the resistance of frozen crustacean flesh to the development of rancid off-flavours (Castell and Spears 1968) commonly found in fatty fish after short periods of frozen storage. The non-development of rancidity is advantageous because periods of up to 6 months' frozen storage may be required before rock lobsters or prawns reach consumers in the export markets.

Prawns

The rapidly expanding prawn industry in the far north and on the north-east and west coasts of Australia (Fig. 1) requires the application of refrigeration technology to new and unusual situations. During the prawn fishing season in tropical areas, temperatures of 80°F are common, so that fast and efficient cooling of the catch is essential. In the early stages of exploitation of the Gulf of Carpentaria fisheries most of the fishing fleet consisted of vessels that came from Queensland and Western Australia, and crushed ice was used for cooling the catch during transport. Ice is a suitable refrigerant for short journeys only and the shortage of suitable fresh water made ice scarce and expensive. Some larger vessels and some of the shore processing plants made sea-water ice, which performed satisfactorily, but the disadvantages associated with ice led to radical changes in handling methods. A revolution has come with the use of refrigerated sea water (R.S.W.) and of salt-reinforced R.S.W. (superchill) for cooling purposes on board the fishing vessels and for storage at the shore plant before freezing.

R.S.W. holding was first employed by the salmon 'packers' operating on the Canadian Pacific salmon run, as a substitute for the icing methods used prior to 1961 (Roach *et al.* 1967). Much detailed work has demonstrated the superiority of this method of holding compared with icing; fish are cooled more rapidly and thoroughly and a more uniform temperature is maintained with a consequent improvement in fish quality. R.S.W. holding dispenses with the labour involved in stacking and icing, and iced fish lose considerable amounts of body fluid as a consequence of the pressure exerted by the stack. Icing methods are not considered satisfactory in the Australian tuna industry and in almost all fishing situations R.S.W. has been widely adopted. It is used in the prawn, shark, and snoeck fisheries and for the on-shore buffer storage of Australian salmon before canning.

R.S.W. storage tanks are most commonly constructed of stainless steel in the prawning industry, but waterproof plywood tanks sealed with fibreglass and resin find extensive use elsewhere. The tanks are cooled by mechanical refrigeration units, the capacity of which is related to the fish-holding capacity. A convenient ratio is 1 ton of refrigeration to each 4 tons of fish. In practice the tank is about half filled with sea water, which is circulated through an external heat-exchanger. A temperature of 28 ± 1°F is maintained. To prevent layering in the tank and, in some cases, build-up of ice, some form of stirring is maintained; recirculation of the sea water is the best method. A centrifugal pump circulates the sea water through a high-capacity wire-mesh strainer, thence to the heat exchanger and back to the tank. During installation provision is made for introducing chemical cleaners and sterilizing solutions into the piping and tanks and for discharge of used sea water overboard. For the small prawning vessels some *ad hoc* modifications were made to the original R.S.W. system to overcome difficulties in operation and a high salt content in the immersed prawns. Instead of recirculating the chilled sea water over externally placed heat exchangers, stainless steel chiller plates were placed directly into the R.S.W. tank and a stirring system, if one was used, often consisted of a perforated air hose through which compressed air was pumped. A continuous stream of air bubbles passed up and over the chiller plates. When ice formed around the chiller plates, as it often did, effective circulation stopped and over-running of the compressor resulted in rapid deterioration of the unit. When icing of the heat exchangers occurred the prawns were exposed to an increased concentration of salt. In addition, the operator then usually added more salt to lower the freezing point of the brine to prevent the build-up of ice. A concentration as high as 17% salt has been found in the R.S.W. tanks in some vessels (Montgomery, Sidhu, and Christie 1970). Salt may also be added to R.S.W. to increase the firmness of the prawns and also for its 'preservative' effect. The addition of salt has resulted in concentrations as high as 7% in prawns whereas the normal salt content is 0·4%. Changes in the flesh proteins occur in prawns containing more than 5% salt and they become extremely tough and rubbery, apart from being unacceptably salty. High salt contents may be reduced by washing the prawns in fresh water, but washing does not alter the tough texture. Prawns with salt contents of more than 2·5% are not accepted for export.

Freezing Prawns at Sea

Freezing prawns at sea enables the catch to be kept in good condition for longer periods than is possible by using R.S.W. Freezing also avoids the exchange of water-soluble solids of the prawn flesh and salt, which takes place when prawns are immersed in R.S.W.

Freezing methods include the use of ice plus salt mixtures, brine spray, brine immersion, and partial freezing or superchilling. It is doubtful whether ice plus salt mixtures are used for the shipboard freezing of other fish or crustacea, but this method is used extensively for the transport of prawns from the Gulf of Carpentaria to southern and eastern processing areas where labour and fresh water supplies are not as limited as they are in northern Australia. The prawns are shipped in steel-reinforced fibreglass or plywood containers insulated with polyurethane foam. The ice–salt mixture freezes hard and forms a blanket above the prawns which keep in good condition for journeys of 3–5 days. Uptake of salt may be considerable during transport but washing in fresh water at the processing plant reduces the level to less than 2·5%. Brine immersion freezing, or freezing in a brine–glucose mixture, is the method of choice for most shipboard installations while the superchilled R.S.W. storage of prawns (and fish) is common practice; only rarely have plate or blast freezers been installed on prawn-fishing vessels.

Locally designed brine-immersion freezing units have been installed on a number of vessels operating in the Gulf of Carpentaria and north-east coast prawn fisheries. The vessels must be large enough, however, to accommodate R.S.W. tanks for storage before freezing, and a post-freezing frozen storage hold. The size of the refrigeration units employed on these vessels limits effective freezing to from 80 to 160 lb prawns per hour. The use of saturated sodium chloride solutions limits the lowest temperature obtainable in brine-immersion freezers to −6°F, but brine freezing affords rapid freezing and can be more easily installed and operated than either air-blast or plate freezing. Salt uptake by prawns during brine freezing can be limited to less than 1% by briefly dipping the prawns in fresh water before and after immersion in the chilled brine. Rinsing the prawns after freezing is more effective in reducing salt uptake than the pre-freezing rinse, although both are desirable.

Rock Lobsters

Commonwealth Export (Fish) Regulations require the lobsters to be live and active at the time of processing to ensure they are fresh. The regulations prescribe time–temperature conditions to be attained during freezing, and the frozen storage temperature: 12 hr to reach a temperature of not more than 20°F, and the temperature of frozen storage should not exceed −5°F. All rock lobsters for export are frozen before *rigor mortis*, characterized by stiffening of the muscles, occurs. Lobster muscle takes about 12 hr at 68°F to reach *rigor mortis* and after 36 hr considerable breakdown of the muscle occurs, accompanied by the production of the volatile bases trimethylamine and ammonia, and by bacterial invasion of the tissue.

Rock lobsters are delivered to the processing plant packed loosely in jute sacks. The head part (cephalothorax), together with the digestive tract, is removed, the tails are washed in fresh water, trimmed, and packed in 20-lb lots in boxes ready for blast freezing. To achieve freezing within the required time of 12 hr adequate air space between the stacked boxes and air ingress to the contents must be provided. Wooden containers are often used, but corrugated cardboard cartons are cheaper. These containers must have holes in the sides to allow the cold air blast to reach the interior of the container.

The Australian States apply similar requirements regarding the fitness of lobsters for human consumption. For the N.S.W. market, lobsters must be either alive or cooked. If cooked, the tail must be firm and must curl under the head. If the tail hangs loosely, a condition known as 'droptail', it is likely the lobster was dead before cooking. Since the flesh spoils rapidly after death, droptail indicates the flesh may have undergone some decomposition; odours of ammonia are present under these circumstances.

Rock lobsters die if they are exposed to temperatures much below 40°F for even a short time, so ice or other cooling is not used during transport of the live animals. They suffocate if closely packed together in oxygen-deficient sea water, but good survival is achieved if the animals are loosely packed in jute sacks where air circulation is adequate. In this form they are transported from the catching vessel to the processing plant.

Alternative Freezing Methods

A saving of time and labour would result if rock lobster tails were frozen in less than the 12–24 hr now required for blast freezing and some improvement in quality might be expected as a result of faster freezing. Plate and brine-immersion freezers usually give faster rates of freezing. Experiments have shown that rock lobster tails in standard containers took 165 min to cool from 64°F to 7°F when frozen in brine at an average temperature of −4°F. In a plate freezer tails packed in a single layer in aluminium trays took 98 min to cool from 59°F to 7°F. The salt content of the brine-frozen tails was lower than 2·5%, the level at which lobster becomes unacceptable.

Frozen Storage and Transport

Experimental work with fish and crustacea has shown that for storage for periods longer than 3 months a temperature of −22°F or certainly not higher than −17°F is desirable. Storage temperatures in actual practice in some commercial installations are much higher than this, for example 0–5°F is about the lowest temperature that can be expected commercially. For export to the United States or Europe prawns and lobster tails should have a storage life of 6 months to give time for shipping, storage, and distribution. Fluctuations in storage temperatures should be avoided because they are often more damaging to the quality of fish and crustacea than storage at too high a temperature. New frozen storage holds on board naval and fishery research vessels have demonstrated the advantages of a frozen storage temperature of −22°F for fish and crustacean products, and it seems likely the trend to lower storage temperatures will continue.

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Corrosion Control in the Food Industry*

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Foods are most complex and variable in chemical composition, many are readily spoiled by microbial action, and all are intended to be consumed by humans or animals. These points, in addition to the usual aspects of economic and engineering feasibility, influence the food industry's approach to corrosion control. It is seldom possible, for instance, to identify one constituent in a food as the primary cause of corrosion, and the range of corrosion-resistant materials available to the industry is restricted by the requirements that they be non-toxic, harmless to the food, and amenable to sanitizing operations.

Corrosion of Factory Buildings

Most food plants have sloping concrete floors, steel-framed walls, and roofs covered with asbestos cement or aluminium sheets; sometimes the walls are cement rendered or tiled brick. The upper parts of most food-processing buildings are exposed to steam and vapours from jam boiling, meat scalding, caustic peeling of fruit, and similar operations. The walls are also exposed to wash water containing detergents and up to 30 p.p.m. chlorine. These conditions seldom cause troublesome corrosion of the structural steelwork if it is correctly prepared and painted when erected and if it is designed so that it can be repainted periodically. Primers based on red lead should not be used in food plants because lead is toxic and because these primers do not perform well in steamy atmospheres; primers containing zinc are usually satisfactory. Paints based on chlorinated rubber, epoxy resins, or epoxy- or polyurethane-modified bituminous materials are suitable for finishing coats. Unmodified bituminous paints and alkyd-based paints are not recommended. Advice should be obtained from a reputable paint manufacturer before a protective system is selected.

The concrete floors of most food-processing plants usually show the most obvious signs of corrosion, especially in those areas where food is spilt. It is not uncommon to find the rough metal aggregate exposed by the corrosive action of food constituents such as fruit acids or by the products of microbial action on the spilt food. Although meat and milk have pH of about 6 the concrete floors of plants processing these foods are rapidly attacked, apparently by the action of fatty acids and, in the case of milk, lactic acid.

In most fruit-processing plants little is done to prevent corrosion of the concrete floors apart from periodically hosing the problem areas. When the area becomes too badly corroded it is resurfaced with concrete during the off-season.

Meat-works, breweries, and other plants that operate throughout the year usually have corrosion-resistant floors in vulnerable areas. These areas are often covered with quarry tiles or dairy brick, steel plates, or monolithic coatings of epoxy- or polyester-based materials. The resistance of these floors depends particularly on water and corrosive materials not being allowed access to the concrete base slab. For tiles and plates the concrete base slab should be finished to the required slopes with a wood-float and then covered with a membrane of hot-melted asphalt. Monolithic coatings should be applied directly to the concrete after acid etching and washing to expose the aggregate. Tiles and plates should be laid so that the joints do not collect water or food. At present the best jointing materials seem to be plastics based on furan and epoxy

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resins but new materials are under test. Floors protected with tiles, plates, or monolithic coverings should not be exposed to high temperatures because they may develop micro-cracks and subsequently fail.

Plastic materials for electrical fittings, conduit, bulk bins, conveyor buckets, and other items have eliminated many corrosion problems in the food industry although care is always needed to select non-toxic plastics if they may come in contact with the food. The U.S. Food and Drug Administration has, for instance, approved certain polyester plastics for use in contact with foods.

Corrosion of Processing Equipment

Many items of equipment that are exposed to corrosive environments in the food industry are made mainly of mild steel. Conveyors, cookers, retorts, and can closers are often exposed to heat, water, and oxygen, so the main type of corrosion is rusting. Protection of the outside surfaces of such equipment is usually obtained by painting with glossy industrial paints which give easily cleaned, attractive finishes. The inside surfaces of such items as can-sterilizing retorts that are several times a day exposed in turn to steam at temperatures up to 250°F, chlorinated cooling water, and moist air, are usually painted with aluminium-pigmented modified bituminous paints.

Cathodic protection based on impressed direct currents or sacrificial anodes is used in some hydrostatic cookers for canned foods and in cascade pasteurizers for canned and bottled beer. Local experience indicates that cathodic protection is not fully effective, probably because these items have complex shapes, and marked differences occur in temperature and level of oxygenation from one point to another. Although it is a major job to dismantle machines like these for internal painting, this procedure seems to give the best protection.

Few metals or alloys are used for making those parts of the processing equipment that contact the food. Stainless steels are now widely used, but some equipment is made from tinned steel, nickel-plated brass, or unprotected mild steel. Metals such as cadmium and lead are not used because they are toxic, copper is seldom used because it causes discoloration or other undesirable changes, and most other inert metals are expensive or not readily available. Aluminium is little used, probably because it is not easy to weld and because it is corroded by some foods.

Although information is available about the corrosion resistance of stainless steels in foods and in food constituents, unsatisfactory types of steel are sometimes used for particular applications. Faulty design or faulty fabrication and incorrect cleaning procedures are other causes of corrosion of stainless steel equipment in the food industry. For instance, complaints that stainless steel had rusted were made when equipment was cleaned with steel wool.

Corrosion of Unlacquered Containers

The most extensive developments in corrosion control in the food-processing industry concern tinplate and aluminium cans. The shelf life of many canned foods is determined by how rapidly and in what way the product corrodes the can. Can corrosion reduces the shelf life of aggressive products such as acidified beetroot, berry fruits, and many beverages to about one year. Some canned meats with pH of 6·0–6·5 corrode tinplate at an appreciable rate and shelf lives may be as short as two years in some instances.

Modern tinplate is made so that it is as resistant to corrosion as possible. Steel strip of closely controlled chemical and physical properties is electroplated with tin and the resultant crystalline deposit is 'flow-brightened' by melting for a short time, often in an induction furnace. During flow brightening a layer of alloy, $FeSn_2$, is formed between the base steel and tin coating. The bright strip is treated in an electrochemical bath to give oxide films having specific characteristics and finally a film of oil about 10 molecules thick is applied. The average thickness of the tin layer ranges from 0·0000606 in. to 0·0000152 in. Even the best commercial tinplates have base steel exposed at imperfections in the tin layer.

Under the anaerobic conditions that are established in unlacquered cans within a few days of processing, tin is usually anodic to steel, so tin slowly corrodes and cathodically protects the exposed steel. The shelf life of the can depends on how long sufficient tin remains on the can surface to maintain cathodic protection. The rate of corrosion of unlacquered tinplate partly depends on the amount and form of the $FeSn_2$ alloy. If the

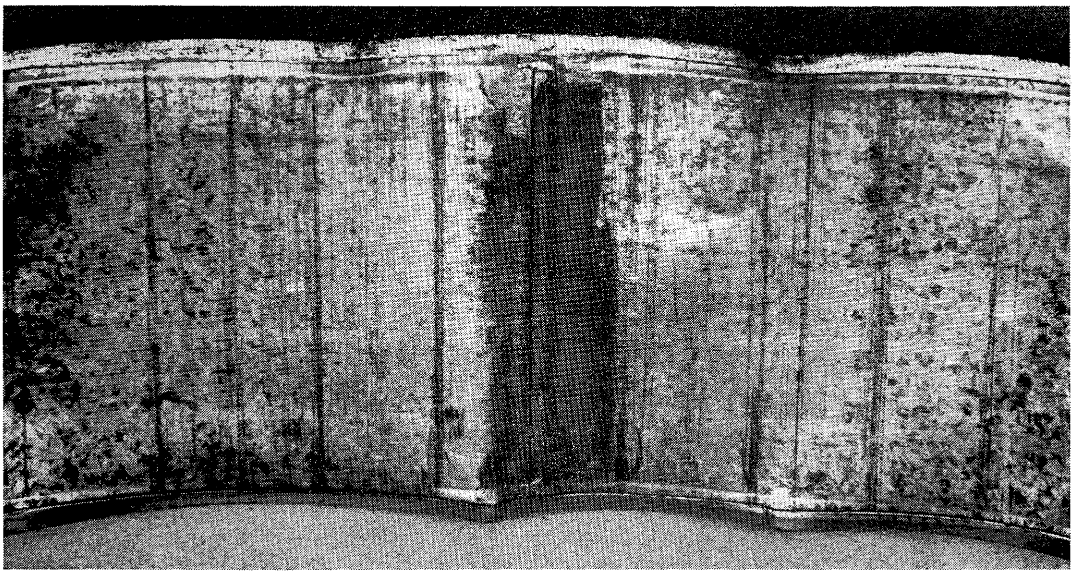

Fig. 1.—Preferential detinning of the side seam of a can by tomato soup.

alloy layer forms a protective covering on the base steel the corrosion resistance is greater than in tinplates having a discontinuous alloy layer. Tinplate manufacturers try to produce plate with the desired type of alloy layer without using unnecessarily large amounts of tin in forming the alloy.

The oxide films on the tin surface also affect can performance. Cathodic dichromate treatments give stable films that resist corrosion by mildly aggressive foods so that detinning will take place only where the film is weak or damaged. The oxide film near the side seam of the can is modified by the heat of soldering so that corrosion of the tin coating is concentrated in this area. This leads to rapid detinning of the side seam (Fig. 1) and the cans quickly become unsalable. For mildly aggressive products, tinplate having a less stable oxide should be used so that slow, evenly distributed detinning will take place and a normal shelf life will be obtained.

Corrosion of Lacquered Containers

Many foods are packed in internally lacquered cans because the products are highly corrosive, because dissolved tin or iron adversely affects the product, or because sulphide from the food causes blue-black staining of the tinplate. Epoxy-based stoving lacquers are commonly used for protecting tinplate from corrosion and they have some screening action against sulphide staining. Epoxy-based lacquers have good mechanical properties and adhere well to tinplate. Phenolic-based lacquers containing zinc oxide are commonly used to prevent sulphur staining and some use is being made of aluminium-pigmented lacquers to hide sulphur staining. White pigmented acrylics are sometimes used, especially in aluminium cans.

Lacquer is applied by roller coating flat tinplate sheets which are then stoved, cut into ends and body blanks, and made into cans on high-speed machinery. The lacquer films suffer some mechanical damage, especially along the side seams of the cans, and these points of damage are prone to corrosive attack. The side-seam area of cans intended for particularly aggressive products are often sprayed with lacquer immediately after the side-seam soldering operation to repair fabrication damage.

Aerated drinks, many of which contain depolarizing pigments and are very corrosive, are packed in cans which have the entire surface repair-lacquered by spraying after one end is seamed to the body. Aluminium ends having easy-open features are protected by a thick coating of lacquer applied by spraying after the end is seamed to the body. Quality control tests for beverage cans include measurement of lacquer porosity. This is done by measuring the current flowing at a fixed potential between a central electrode and the can when the can is filled with a dilute salt solution. Similar tests are applied to drawn and ironed aluminium beverage cans that are spray lacquered after fabrication.

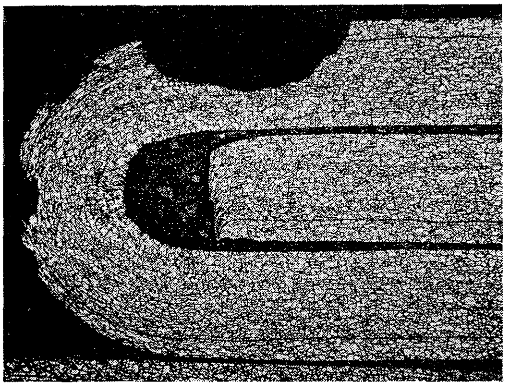

Fig. 2.—Section of the side seam of a can showing pitting corrosion of the base steel.

Electrochemical tests such as polarization resistance measurements are used to measure the corrosivity of soft drinks. These tests are applied to new formulations and are also used to determine the efficiency of corrosion inhibitors. Minor variations in composition may alter the corrosivity of a product, so it is desirable to evaluate test packs before commercial production is undertaken. Some spray residues at a concentration of a few parts per million change the corrosion process in canned fruit from detinning to pitting of the base steel (Fig. 2). Minor variations in the composition of canned meat loaf markedly alter its corrosivity.

Tinplate cans are susceptible to external corrosion, especially rusting, if they are exposed to liquid water and oxygen. Large cans of solid products that require long periods to cool in water after heat sterilization may rust during cooling, especially if the water is hard and oxygenated. The addition of 600–1000 p.p.m. sodium or potassium nitrite to the cooling water prevents rusting in most instances. Chromates are also effective but they are toxic and cause skin complaints and are therefore not recommended.

Liquid water may condense on cold cans if they are exposed to warm humid air and rusting may follow. Condensation may occur in inadequately insulated and sealed warehouses and during transport, especially when cold cans are shipped through tropical areas. Fibreboard cartons may contain sufficient moisture to result in condensation if stacks of cartoned cans are subjected to temperature gradients. Cans may be protected from condensation damage by overwrapping the stacks with plastic film or by maintaining the temperature of the cans above the dew point. Cans for the armed services are externally lacquered; the use of oils or corrosion-inhibiting chemicals seldom gives useful protection.

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News from the Division

FRL, Food Research Laboratory; MRL, Meat Research Laboratory; DRL, Dairy Research Laboratory; PPU, Plant Physiology Unit

Appointment of Officer-in-Charge

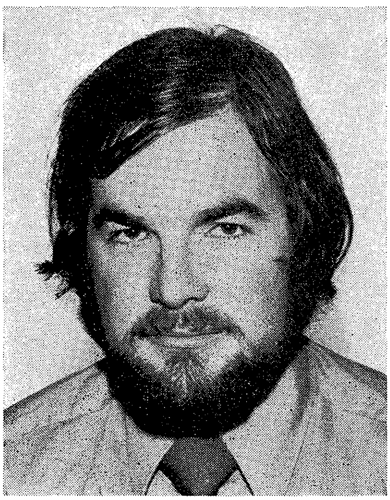
On October 1, 1971, Mr J. F. Kefford, Assistant Chief of the Division, became Officer-in-Charge of the Food Research Laboratory at Ryde. The appointment means that Mr Kefford takes over from Mr M. V. Tracey those responsibilities relating specifically to the FRL.

The Division of Food Research consists of three laboratories (DRL, FRL, and MRL), each now administered by its own Officer-in-Charge, and a Headquarters group responsible for policy, administration, and coordination at the Divisional level. This group consists of the Chief, Associate Chief, Divisional Secretary, and Secretarial Assistant.

New Appointments

Early in December 1971 FRL appointed Mr R. L. McBride as Experimental Officer to take charge of the work of the Taste Test Laboratory.

Mr McBride completed in 1969 a B.Sc. (Hons.) at the University of Canterbury, New Zealand, where his training was mainly in psychology and statistics and included psychometric scaling of taste sensations.



Mr R. L. McBride

Mr McBride was previously employed as a research assistant in private industry, one of his assignments being the optimum utilization of computers. With this background, Mr McBride should prove a valuable addition to the team engaged in the Division's programme of tasting research.

Dr K. J. Nicol was appointed as Experimental Officer at FRL on September 27, 1971, to investigate the biochemical aspects of the problem of bitterness in processed orange juice. Dr Nicol is a graduate of the University of New South Wales, where he also obtained his doctorate.

Mr B. Entsch was appointed as Experimental Officer at the Division's Plant Physiology Unit at Macquarie University. Mr Entsch obtained a B.Sc. degree from the University of Queensland in 1963 and an M.Sc. degree from the same university in 1966. He is completing Ph.D. requirements at Macquarie University.

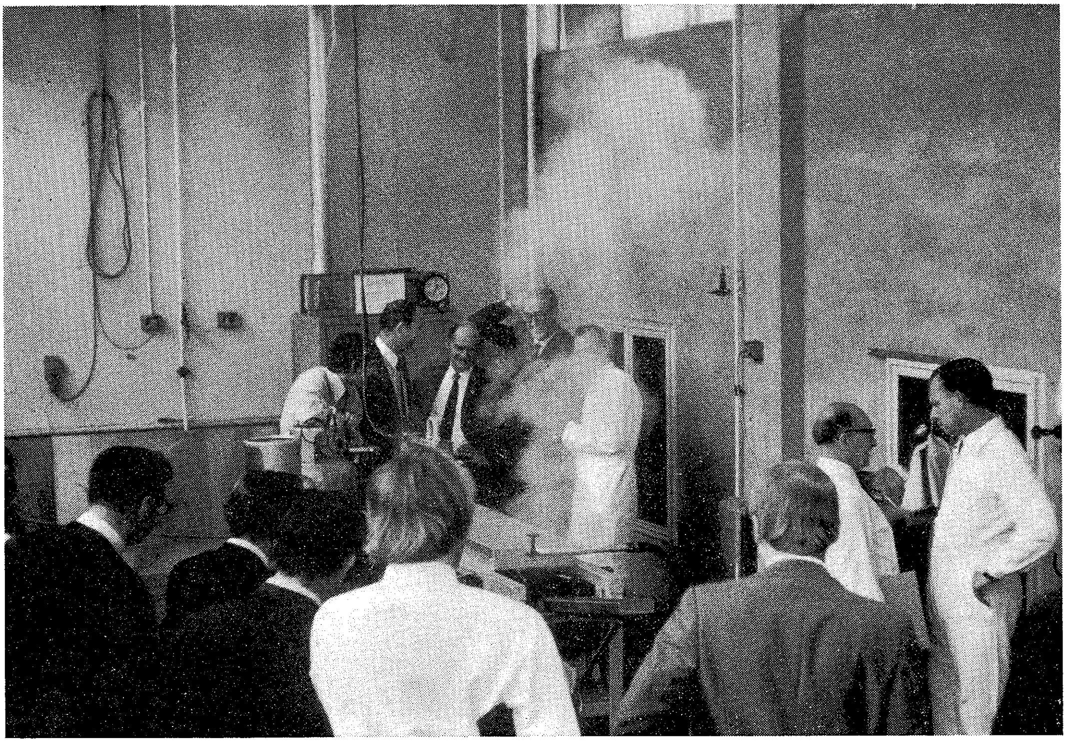
Mrs J. H. Ruello was appointed as Experimental Officer at FRL on November 1, 1971, to participate in the research programme on the biochemistry, chemistry, and processing of prawns. Mrs Ruello holds an M.Sc. degree from the University of Sydney.

Visiting Workers

In mid August Dr Gloria Perry, Post-Doctoral Fellow of the Medical Research Council of Canada, joined PPU as a guest worker for approximately 12 months. She will study the action of carbonic anhydrase in photosynthesis in a joint project with Dr D. Graham.

General

Dr J. K. Raison of PPU and Dr J. M. Lyons of the University of California, Davis, have been awarded the 1971 AIBS–Campbell (U.S.A.) Award for their paper 'Oxidative activity of mitochondria isolated from plant tissues sensitive and resistant to chilling injury'. The award carries a cash prize of



The Flame Sterilization Workshop in session.

$US1500 and a bronze medal. Dr Raison was presented with his share of the award by Dr P. Shea, Manager, Agricultural Research and Processing Department, Campbell Soups (Aust.) Pty. Ltd., at a ceremony at FRL on November 10, 1971.

The title of Honorary Professorial Fellow has been conferred by Macquarie University on Dr R. M. Smillie, Leader of the Plant Physiology Unit.

Mr L. E. Brownlie, Leader of the Industry Liaison Section at MRL, has been appointed to the Microbiology Committee of the American Meat Science Association.

Miss E. A. Chapman, PPU, and Mr R. J. Steele, FRL, have been awarded Ph.D. degrees by the Universities of Sydney and New South Wales respectively.

Mr J. J. Macfarlane, Leader of the MRL's Meat Science and Technology Section, visited meat research organizations in Britain, Sweden, Denmark, Germany, Ireland, U.S.A., Canada, and Japan during September and October 1971. His discussions centred around the production of meat of improved tenderness.

AIFST/CSIRO Flame Sterilization Workshop

This Specialist Course (referred to in this Quarterly, Vol. 31, No. 3) took place at Ryde on November 18 and 19, 1971 and was over-subscribed with 35 participants, mainly senior technical executives from the food industry. In addition to speakers from Australian industry and CSIRO, lecturers to the Workshop included M. Jacques Greder, Export Manager of J. J. Carnaud et Forges de Basse-Indre, Paris.

Printed lectures from the Flame Sterilization Workshop, designated Specialist Courses for the Food Industry No. 2, are now available at $5 per copy from Mr G. Fisher, Technical Secretary, CSIRO Division of Food Research, P.O. Box 52, North Ryde, N.S.W. 2113.

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