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Atmosphere Control

in Storage and Transport of Fresh Fruit and Vegetables

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Controlled-atmosphere (C.A.) storage is the term applied to the storage of fruits and vegetables in an atmosphere containing more carbon dioxide and less oxygen than air. This article explains the biological principles on which the practice is based, and describes the methods used to produce atmospheres of the desired composition.

Prime Importance of Temperature

The life of fresh fruits and vegetables after harvest is primarily dependent on temperature. As a rough generalization, based on the effects of temperature on respiration, life is halved by a rise in temperature of about 18°F. However, in practice the effects of temperature are much greater in the lower (cool storage) range; for example, it has been shown that the storage life of Packhams Triumph pears at a temperature of 30°F is double that at 36°F. Temperature not only affects the rate of all the physiological processes of produce after harvest, most of which are by this time aging processes, but also profoundly affects the rate of growth of microorganisms that attack them. Therefore the best method we have of preserving fresh produce after harvest is refrigeration.

However, there are limits to the full use of low temperatures. It might quite properly be thought that the best temperature for long storage would be the lowest temperature that would not actually freeze the tissues. The freezing point of most fruit and vegetables is in the range 28–31°F, so that the lowest safe storage temperature would be in the range 29–32°F. However, this is true only for some kinds. Others are susceptible in varying degrees to 'cold injury', in which exposure to low temperatures, often well above the freezing point, produces physiological breakdown of the tissues, loss of ability to ripen, loss of resistance to microbial attack, or development of off-flavours. In general, tropical fruits are sensitive to cold and must be held at temperatures well above their freezing point, as also must tomatoes, all cucurbits, sweet potatoes, potatoes, and green beans.

Biological Basis of Atmosphere Control

The rate of ripening of fruits and the rate of deterioration of perishable produce is affected also by the composition of the atmosphere around them. By controlling the concentration of the respiratory gases, carbon dioxide (CO_2) and oxygen (O_2), in the atmosphere the life of many fruits and vegetables at a particular temperature can be further increased, in some cases quite spectacularly. Respiration is a process of oxidation and in its simplest form can be represented by the following equation for complete oxidation of a simple sugar:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O.$$

This reaction can be slowed down by withholding O_2 or by allowing the CO_2 produced to accumulate.

The 21% of O_2 normally present in air is usually adequate for maximum respiration. The rate of respiration, and hence the rate of ripening and deterioration of fresh produce, can be reduced by decreasing the O_2 supply, generally most readily by storage in an atmosphere low in O_2. However, to avoid abnormal (i.e. excessively anaerobic) respiration, leading to fermentation and breakdown, the O_2 supply must not fall below a certain critical level which is determined mainly by the rate of respiration and is therefore greater at higher temperatures. This level is also dependent on the time of exposure, lower levels being tolerated for short periods. In cool storage this critical level of O_2 in the atmosphere is about 2% for apples and pears and probably also for many other kinds of produce.

Grierson *et al.* (1965) showed that reduction of the O_2 concentration to 10% halved the rate of respiration of lemons at 60°F. Claypool and Allen (1948) found that a reduction of oxygen concentration to 5% was necessary to halve the rate of respiration of Santa Rosa plums at a temperature of 40°F. The data of Fidler and North (1967) show that at temperatures of 32–35°F, the O_2 concentration must be reduced to below 5% to have any significant effect on respiration of apples. The same authors studied the rates of respiration of Cox's Orange Pippin apples at 38°F in the presence and absence of 5% CO_2 over a range of O_2 concentrations. They found that 5% CO_2 reduced the rate of production of CO_2 by about 45% and the uptake of O_2 by about 25%, independent of the concentration of O_2, so that in this instance the effects of CO_2 and O_2 on respiration were clearly additive.

While most fruits respond to reduced O_2 in the atmosphere by reduced respiration and a delay in commencement of ripening, Young, Romani, and Biale (1962) showed that the avocado, the banana, and the lemon reacted differently to increased CO_2. In the avocado, respiration was reduced and ripening delayed; in the banana, ripening was delayed but respiration was not reduced; and in lemons respiration was actually increased. Thus responses to increased CO_2 are more variable than responses to low O_2.

Skin Coatings

The seat of respiration is in specialized, highly organized bodies within the cell, so that it is really with the internal concentrations of O_2 and CO_2 that we are concerned. These are dependent not only on the concentrations outside the fruit or other organ, but also on the resistance of the organ to the passage of the gases to and from the inside. This resistance is mainly in the skin, and in fruits the passage of the respiratory gases is mainly by diffusion.

In cool storage the internal atmosphere of apples contains about 0·5% more CO_2 and about 0·5% less O_2 than there is outside. These differences are greater at higher temperatures, when respiration is more rapid. To some extent the internal concentrations of CO_2 and O_2 can be varied and storage life increased by adding an artificial resistance to the natural resistance of the skin to the diffusion of CO_2 and O_2, by coating the produce with very thin films of wax or similar materials. Incidentally, the main practical benefit from such skin coatings is usually a reduction of evaporation of water and thus a reduction of wilting.

While waxing to reduce evaporation is widely practised, the safe use of skin coatings to retard respiration and increase storage life is difficult, being dependent on maintenance of a uniform temperature throughout. A coating effective at low temperatures will be damaging when respiration is faster at higher temperatures and, conversely, a coating with a resistance tailored to suit higher temperature conditions will be ineffective at low temperatures.

Early Development of C.A. Storage

Historically, controlled-atmosphere storage had its beginning in England in the work done by Kidd and West, of the staff of the Food Investigation Board, immediately after the first World War. They had studied the effects of atmosphere composition on the activity of mustard seeds and had found that both higher CO_2 and lower O_2 concentrations depressed respiration and delayed germination. This led them to find out if, by atmosphere control, apples could be kept longer in the unrefrigerated barns and cellars then in general use. Successful results led to atmosphere control being combined with temperature control, and by the mid twenties the concept and practical application of refrigerated gas storage were well established. Research continued in England and was soon begun in other countries, and C.A. storage of apples and pears is now widely practised throughout the world. It is particularly valuable in England and in other countries where the main apple varieties are subject to low-temperature breakdown and where temperatures of the order of 38°F must be used to avoid this disorder (Fidler 1965). Most

English apples are now C.A.-stored, as are a large number of the apples stored in Europe.

C.A. storage has been slower to develop in the U.S.A. and in Australia, where low-temperature-sensitive varieties are less important, but about 15 million bushels of apples are now being C.A.-stored in the U.S.A. and in Australia some quarter of a million bushels of apples are being kept in C.A. storage during this season (1968). In very recent years atmosphere control has been extended to other produce, and it is being applied to storage during transport as well as to ordinary storage (Smith 1963). These developments are the result of widened research aimed at providing basic biological information, and of engineering and other technical progress.

Methods of Atmosphere Control

The first requirement is a sufficiently gas-tight envelope around the produce. This may be a large gas-tight store, a ship's hold, a road or rail vehicle, a movable container, a plastic sheet stack cover in a cool store, a sealed plastic film bag as a box-liner, or even a small retail unit package. The second requirement is some means of maintaining the concentration of CO_2 and O_2 at the desired levels.

At first, 'gas storage' of apples was simply a system of ventilated gas storage in which the gain was due almost entirely to the accumulation of CO_2 from fruit respiration, which was allowed to accumulate to the desired level and then kept at that level by simple ventilation with outside air. Common atmospheres aimed at were those with 5–10% CO_2 and, correspondingly, 16–11% O_2, since in the presence of several per cent of CO_2 the respiratory quotient (volumetric ratio of CO_2 produced to O_2 consumed) is about unity for English apples held at 38°F. However, some important varieties of apples and pears are damaged by CO_2 levels even as low as 3%.

As research revealed more biological data on the benefits of low oxygen levels, attention was directed towards devising practical methods of maintaining a low level of O_2 as well as a certain level of CO_2. One requirement was a more gas-tight space, because the rate of leakage from the storage space depends primarily on the difference between the external and internal partial pressures of the gas concerned. Another was some means of absorbing excess CO_2 produced by the fruit.

Removal of CO_2 is now achieved by passing portion of the air, as required, through a scrubber containing an alkaline solution such as caustic soda, potassium or sodium carbonate, or ethanolamine; or more simply by water spray, the CO_2 absorbed from the spray water being removed by warming the water and aerating it with outside air. The simplest scrubber of all is one in which the storage atmosphere comes into contact with bags of fresh hydrated lime.

As a result of the developments mentioned above, atmospheres containing 2–5% CO_2 and 2–3% O_2 have been shown to be more effective than atmospheres depending on control of CO_2 alone. They are now widely used for apples and pears, and have been found suitable for many other kinds of produce under refrigeration. The gain from use of controlled atmospheres is not limited to longer life in store by retarding softening, yellowing, and other ripening and aging changes in the fruit; other important advantages are much slower ripening and extended shelf life after removal from storage. Because a gas-tight store is also a more efficient store, humidities in the store are higher and shrinkage is less. This factor also contributes to the excellent maintenance of original fresh condition that is possible with C.A. storage.

Research around the world has shown little promise for the long storage of stone fruits and citrus, other than lemons, in controlled atmospheres. However, C.A. storage is likely to be useful for the short-term holding or transport of many kinds of fresh produce, particularly where optimum refrigeration is not possible, or to extend the life of very perishable items such as berry fruits.

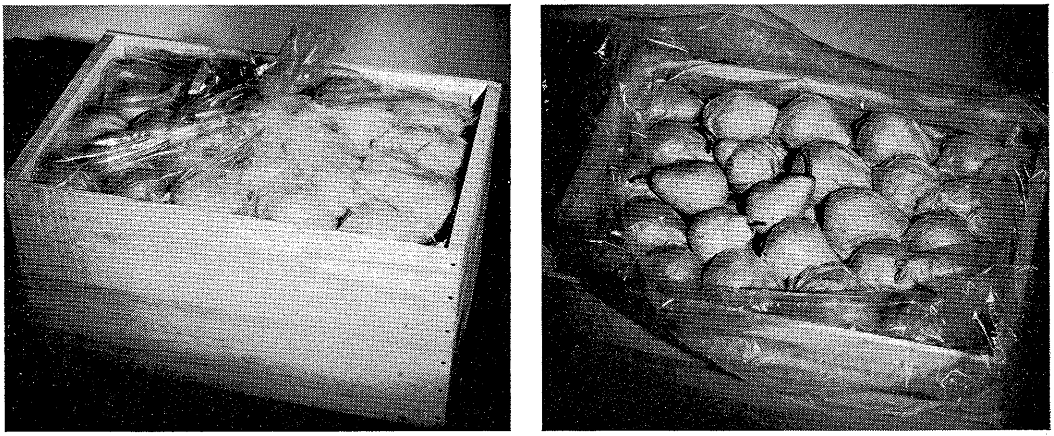
Operation of a C.A. Store

It is not easy to make a cool store sufficiently gas-tight. The gas-tightness is commonly measured by putting in 12–15% of CO_2 and running the room at the cool-storage temperature with fans on, and then measuring the rate of fall of the CO_2 concentration. The gas efficiency is the percentage of the original concentration remaining after 24 hr. For operation at an oxygen level of 2–3% it is necessary to have a gas efficiency of 0·95 or better (at least 95% remaining after 24 hr).

The gas-tightness can also be measured by following the rate of fall of a small positive pressure of air built up in the room. A pressure of $\frac{3}{4}$ in. water gauge should be built up first, and this should not fall to less than $\frac{1}{2}$ in. in less than 8 min or from $\frac{1}{2}$ in. to $\frac{3}{8}$ in. in less than 5 min. Such a high degree of gas-tightness can be obtained only by use of proper materials and good careful workmanship, particularly in sealing all service entries, holes, joints, and cracks. A hole only $\frac{1}{2}$ in. square could make a store useless for scrubbed storage (Anon. 1965).

Plastic Bags and Stack Covers

Polyethylene film bags are being used increasingly as box-liners to provide what is called 'in-case C.A. storage'. The CSIRO Division of Food Preservation has shown that $1\frac{1}{2}$ mil low-density film (0·0015 in. thick), when in the form of a sealed bag inside a bushel box or carton, automatically provides atmospheres generally suitable and safe for apples and pears at cool storage temperatures,



In-case controlled-atmosphere storage of pears in sealed polyethylene film bag case-liner. *Left*, bag closed. *Right*, bag open to show fruit.

though O_2 levels vary much more than the CO_2 levels (Scott *et al.* 1964). The rate of respiration of the fruit increases considerably when it is removed from cool storage to higher temperatures, but because the gas resistance of the film remains the same the bags must be punctured to prevent the rapid build-up of a damaging atmosphere inside them. Similarly, after fruit is packed into bags the bags should not be sealed while the fruit is hot (above 70°F), and subsequent cooling should be quick. Ideally, apples and pears should be pre-cooled before they are packed in sealed polyethylene bag liners. Plastic stack covers can also be used in an ordinary cool store but, apart from problems of sealing, there are problems of heat transfer and cooling.

The use of external generators is a recent development that has given a considerable impetus to the spread of C.A. storage. Controlled combustion of a suitable fuel (usually propane or petroleum gas) followed by water washing, 'scrubbing', and, commonly, a final adjustment of the composition of the gas by adding a small amount of air, permits the required atmosphere to be fed directly into the room. The advantages of this system are a quick 'pull-down' of O_2 level in the store, rapid re-establishment of the required atmosphere after opening the room, and ability to use a room not gas-tight enough to operate in the ordinary way. Following tests by the Division of Food Preservation in 1966, external generators are now being operated commercially in Australia at some 20 stores.

Atmosphere Control in Transport

The use of atmosphere control in the transport of fresh produce is a very new development and will probably fit in well with containerization. Before World War II, again as a development from laboratory research, much of it by CSIR (as CSIRO was then), chilled beef was being extensively shipped overseas in an atmosphere of 10% CO_2 at a temperature of 29°F. This obviated the need to ship beef in the hard-frozen condition; it was an important development because after thawing, frozen beef suffers from excessive 'drip' and develops a dark colour. The CO_2 greatly retarded the growth of bacteria on the surface of the meat; in air such growth limits the storage life of chilled meat to 3–4 weeks, even under the best conditions of slaughtering hygiene. The chilled beef trade did not develop again after the war, but in the last 2 or 3 years atmosphere control has been applied successfully to the transport of fruit. It is being developed in two directions, one being the use of sealed plastic film bag liners in standard packages, and the other involving control of the atmosphere in large containers.

The use of polyethylene bags in the refrigerated transport of apples and pears is a logical development from the successful use of these bags in cool stores. Pears in polyethylene have been shipped from North America to Europe for some years now, and in 1968 considerable quantities have gone from Australia to Europe, following successful export trials last season. The developments in Australia have been based on research in the Division of Food Preservation.

During 1967 packing in sealed polyethylene bags was extended to bananas by the United Fruit Company, which sent a large shipment from Central America to New Zealand, and in Australia by CSIRO and other research workers at Ryde (Scott and Roberts 1966). The American consignments to New Zealand were shipped under refrigeration at a temperature of 53°F, but work in Australia is concerned more with long-distance rail transport without refrigeration. Bananas respond very well to atmosphere control, and packing in sealed $1\frac{1}{2}$ mil (0·0015 in.) polyethylene film bags can double the transport life of green bananas even under summer conditions. Because the saturated atmosphere in the bags encourages the growth of fruit-rotting fungi, practical application of the technique awaits approval by the health authorities of a new fungicide that has given outstanding results in controlling mould in bananas and other fruits.

Atmosphere control in large transport containers has so far involved continuous introduction of gas during the journey or charging the container with the appropriate atmosphere before the journey, with no further introduction of gas. In the latter method generators are commonly used, though either or both CO_2 and nitrogen (N_2) from cylinders is sometimes used, depending on whether the requirement is high CO_2 or low O_2 or both. These technical developments are being pursued most actively in the U.S.A., where the source gases are cheaper than elsewhere.

Response to Very Low Levels of Oxygen

The recent rapid development of the use of liquid nitrogen as a refrigerant in transport has stimulated interest in the response of fresh produce to exposure to 100% N_2 and to very low levels (1–2%) of O_2, both under refrigeration and at higher temperatures. There is a great potential for atmosphere control in the storage and transport of fresh fruits and vegetables and the CSIRO Division of Food Preservation is setting about obtaining the necessary basic biological data. In some preliminary studies with fruit it has been found that at cool storage temperatures apples and pears are not damaged by reducing the level of O_2 to $1\frac{1}{2}$% and that at temperatures in the range 70–80°F green bananas will withstand 2% O_2 for several days. The ability to withstand very low levels of O_2 in the atmosphere is generally inversely proportional to temperature (i.e. to the rate of O_2 consumption by the produce) and the response is also a function of time of exposure.

The U.S. Department of Agriculture has investigated the effect on perishable produce of modified atmospheres produced by the use of liquid nitrogen for refrigeration during transport. Ryall (1963) reported as follows:

- Lettuce at 32–33°F (0°C) in 100% N_2 for 10 days suffered no injury or ill effect on flavour and texture. Darkening of the butts and russet spotting were controlled as compared with storage in 1% O_2 or air.

- Strawberries at 32–33°F (0°C) in 100 or 99% N_2 for 10 days maintained their flavour and had less mould, but were rather softer, than those in air at 32–33°F.
- Spinach in 100% N_2 at 33°F for 4 days had a bitter flavour when cooked.
- Ripe bananas, pink tomatoes, and mature peaches after 4 days in 100% N_2 at 60°F (16°C) had developed abnormal flavours.
- Green bananas and tomatoes in 100% N_2 at 60°F (16°C) for 4–7 days did not ripen and subsequently failed to ripen satisfactorily at 70°F (21°C). With 1% O_2, 99% N_2, subsequent ripening appeared normal but was slower.
- Peaches with 1% O_2 present behaved normally afterwards in air.
- The growth of *Rhizopus*, *Penicillium*, *Phomopsis*, and *Sclerotinia* fungi was almost completely inhibited by 100% N_2, but not by 1% O_2, 99% N_2.

Parsons, Gates, and Spalding (1964), working in the U.S.A., found that some kinds of produce were not damaged by atmospheres of 100% N_2, although others were. Lettuce and strawberries could be stored satisfactorily at 33°F, but green bananas, tomatoes, and peaches, which were stored at higher temperatures, were damaged. In general, pure N_2 was much safer at low temperatures.

Some years ago in Canada, Eaves found that apples withstood 100% N_2 at 42°F for one week. Eaves (1963) shipped apples and pears experimentally in bulk bins lined with Mylar film and carried at ordinary temperatures. CO_2 was kept below 1% by using hydrated lime as an absorbent and the O_2 levels of 1–2% effectively retarded ripening.

Ryall concluded that liquid nitrogen refrigeration of transport vehicles was unlikely to be damaging to most kinds of perishable produce because the chance of maintaining oxygen-free atmospheres was remote and even 1% O_2 is enough under these circumstances for up to seven days.

While it seems that pure nitrogen would not damage a number of kinds of fruits and vegetables held at temperatures below 40°F for a few days, it is clear that further studies are necessary before the method can be considered quite safe commercially. Another approach would be to ensure (by bleeding-in air) that 1–2% O_2 was maintained in the atmosphere in the transport vehicle. This would make liquid nitrogen refrigeration quite safe, provided precautions are taken to avoid freezing of any of the produce.

In general 100% N_2 is not safe but 1% O_2 seems safe for most kinds of fruits and vegetables for short periods at temperatures around 60°F, while at higher temperatures it would be advisable to keep the O_2 level up around 2%. Asparagus appears to be an exception, being damaged in 5% O_2 even at lower temperatures. It has been found that the oxygen requirements of most fruit-rotting fungi are very low and the growth of moulds in 1% O_2 is very little different from that in air. However, their growth is considerably inhibited by CO_2. Cherries are remarkably tolerant of both high CO_2 and low O_2 and respond well to initial exposure to 25–30% CO_2 and prolonged exposure to 10–15% CO_2, or to less than 1% O_2, under refrigeration. Consequently, dry ice has been used successfully in the shipment of cherries. Berry fruits also respond well to relatively high levels of CO_2.

A refrigeration system based on liquid carbon dioxide is currently being developed primarily for use in transport vehicles. It may have some advantages over liquid nitrogen systems; for example, atmospheres containing a desirable concentration of CO_2 can be maintained by bleeding-in some of the spent gas.

While atmosphere control is unlikely to replace refrigeration in the preservation of perishable produce, it will soon play an important part in its storage and transport, especially for those kinds sensitive to low temperatures.

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Oxygen Permeability

of Food Packaging Materials

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Oxygen permeability is an important property of flexible film materials used for the packaging of oxygen-sensitive foods. This article discusses the data accumulated in the laboratories of the CSIRO Division of Food Preservation on the oxygen permeability of a wide range of locally available packaging films, and demonstrates the effect of oxygen permeability on loss of flavour in salted peanuts.

MOST packaged foods are sensitive to oxygen. In some cases oxygen has beneficial effects on quality but in others it induces deleterious changes. For instance, fresh fruit and vegetables require oxygen for their normal metabolic processes. Fresh meat also requires oxygen for the formation of the desirable red pigment oxymyoglobin, but nitroso-myoglobin, the pink pigment of cured meat, is destroyed by oxygen. Oxygen has detrimental effects on the flavour of products such as salted peanuts, potato crisps, and roasted coffee, and it permits the growth of moulds on cheese. Containers for the packaging of these and other oxygen-sensitive foods, therefore, must control the exchange of oxygen between the storage atmosphere and the packaged product.

Containers made from metal and glass are impermeable to gases in the absence of defects such as pinholes and faulty closures. All cellulosic and plastic materials, however, are permeable to some extent when there is a difference in partial pressure of the gas across the material; their relative permeabilities depend on the chemical and physical structure of the material. For instance, copolymers based on polyvinylidene chloride (PVDC) are probably the least permeable of the unsupported plastic films to gases, and polyethylene is one of the most permeable. Under comparable conditions, polyethylene is approximately a thousand times more permeable to oxygen than PVDC.

Ideally, precise data on both the oxygen requirements of the food and the oxygen permeability of the container material are necessary for the selection of suitable containers for specific foods. In practice, the oxygen requirements of foods can be specified in qualitative terms only, whereas data on the oxygen permeability of container materials can be determined accurately in the laboratory. The final choice of material is determined, therefore, from test-pack studies of the food in containers made from several materials the oxygen permeabilities of which are known. The work on salted peanuts, described below, is a typical example of a test-pack study.

Theory of Gas Permeability

The transmission of gases through films may occur by two distinct mechanisms:

- A pore effect whereby the gas flows through small pores in the film;
- A solution–diffusion process whereby the gas dissolves in the film on one side, diffuses through, and evaporates from the other side.

Aluminium foil may transmit gas by the first mechanism only; in the absence of pores it is impermeable. Both mechanisms occur with sufficiently thin plastic films, but most commercial products are pore-free so true permeability occurs by the second mechanism.

The true permeability (P) of a homogeneous film to gas is defined by the equation

$$P = \frac{q.l}{A.t.\Delta p}$$

(Barrer 1951) where q is the volume of gas diffusing through a film of thickness l and area A in time t under a partial pressure difference Δp across the membrane. Barrer also deduced that

$$P = D.S$$

where D is the diffusion constant of the gas in the film and S is the solubility coefficient.

In the literature, gas permeability values are expressed in a variety of units. In this discussion, the units used are cc(s.t.p.) $\times 0 \cdot 001$ in. $\times \mathrm{m}^{-2} \times 24\ \mathrm{hr}^{-1} \times 76\ \mathrm{cm}^{-1}$Hg at specified temperature and relative humidity (R.H.). With coated and laminated films, corrections to unit thickness are not valid, hence values for these materials are reported in cc(s.t.p.) $\times \mathrm{m}^{-2} \times 24\ \mathrm{hr}^{-1} \times 76\ \mathrm{cm}^{-1}$Hg, and details of the material are specified. Some useful factors for the interconversion of the various permeability units used in the literature have been recorded by Selby (1961).

The theory of gas and vapour permeability of films, and the variables causing deviation from ideal behaviour, are discussed by Hennessy, Mead, and Stening (1966).

Oxygen Permeability Measurements

The gas permeability of flexible films is usually determined on small specimens by test-cell techniques. Stocker (1963) has given a useful summary of the methods available. A volume-increase method, illustrated in Figure 1 and described previously by Davis (1964), was used in the present studies.

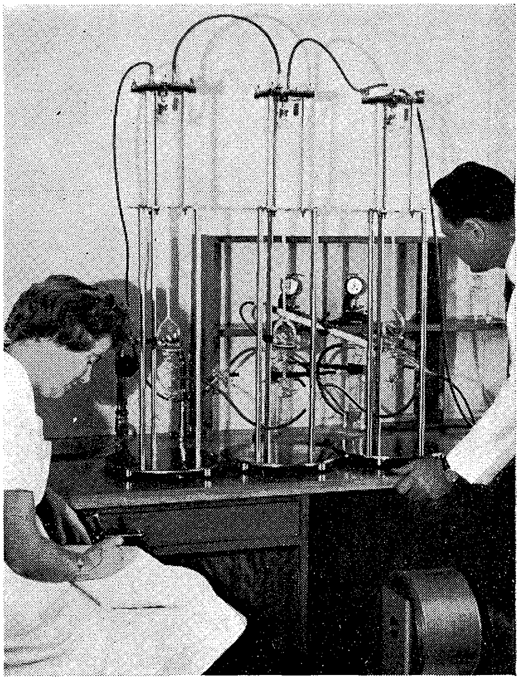

Fig. 1.—Apparatus for determining the gas permeability of flexible films.

Table 1 shows the oxygen permeability of a range of flexible films, determined by the volume-increase method. The test materials were obtained from numerous suppliers and users and are therefore representative of materials currently available to the local food-packaging industry.

The results observed on papers coated with PVDC require further explanation. The barrier properties of these materials are influenced by many variables associated with the composition of the PVDC emulsion, the nature of the paper substrate, and the method of application. The importance of these

Table 1
Oxygen Permeability Values of Some Food-packaging Materials

Material	No. of Batches Examined	Oxygen Permeability (cc(s.t.p.) × m^{-2} × 24 hr^{-1} × 76 cm^{-1}Hg)	
		20°C, 65% R.H.	25°C, 65% R.H.
Homogeneous films			
Polyethylene, low density (0·001–0·002 in.)	6		6900–11,000*
Polyethylene, low density (0·002 in.)	1	6900*	
Ethylene–vinyl acetate copolymer (0·0015 in.)	1		7700*
Vinylidene chloride–vinyl chloride copolymer (0·002 in.)	1	4·2*	
Polyvinyl chloride, plasticized (0·0007 in.)	1		3000*
Polyamide (nylon 11 tubular film (0·0013 in.)	1	220*	450*
Polyamide (nylon 11 tubular film) (0·0026 in.)	1		240*
Polypropylene, unoriented (0·0015–0·002 in.)	2		3500–4300*
Polyethylene terephthalate (0·001 in.)	1		83*
Polycarbonate (0·00125 in.)	1	3100*	
Hydroxy ethyl cellulose (0·0015 in.)	1		10*
Coated films			
300 MSADT cellulose	1		94
300 MSAT cellulose	1		71
300 MSAT cellulose, double ply	1		54
400 MSAT cellulose	3	83–120	59–160
650 MSAT cellulose	1	70	
300 MXDTA cellulose	1	7·1	7·3
300 MXXTA cellulose, double ply	2		1·7–3·1
400 MXXTA cellulose	1	11	6·5
400 MXXTA cellulose	3		6·4–9·2
400 MXXTS cellulose	2	3·7–9·2	
Polypropylene (0·0009 in.) coated on both sides with PVDC	1	6·7	
Polypropylene (0·0009 in.) coated on both sides with PVC	1	610	
Laminates			
300 MSADT/polyethylene (0·001 in.)	1	86	84
300 MSADT/polyethylene (0·00175 in.)	1	87	
400 MSADT/polyethylene (0·00085 in.)	1	110	
300 MXDTA/polyethylene (0·001 in.)	1	3·6	8·8
300 MXDTA/polyethylene (0·00175 in.)	1	7·1	
300 MXDTA/polyethylene (0·00175 in.)	1		13
300 MXXTA/polyethylene (0·0015 in.)	1		13
350 MXXTS/polyethylene (0·00175 in.)	1	5·9	
300 MXXTS/polyethylene (0·0025 in.)	1	8·6	
Polyethylene terephthalate (0·0005 in.)/polyethylene (0·0015 in.)	1	58	
Polyethylene terephthalate (0·0005 in.)/polyethylene (0·002 in.)	5		100–150
Polyethylene (0·00175 in.)/polypropylene (0·0007 in.)	3		1800–2100
PVDC-coated papers			
Glassine coated with PVDC (26 g/m^2)	2	5·0–7·7	
Glassine coated with PVDC (38 g/m^2)	1	4·4	
Glazed imitation parchment coated with PVDC (25 g/m^2) on one side and polyethylene (0·001 in.) on the other side	1	120	
Glazed imitation parchment coated with PVDC (17 g/m^2) over polyethylene (0·001 in.)	1	2·3	

* Values corrected to unit thickness of 0·001 in.

factors has been discussed by Avery (1962), Poschmann (1965), and Dierinckx (1967).

The results in Table 1 show that very low oxygen permeability values can be achieved with PVDC coatings of 26–38 g/m^2 applied to a smooth-surfaced, non-absorbent substrate such as glassine, or with a coating of 17 g/m^2 on glazed imitation parchment previously coated with polyethylene. The beneficial effect of a pre-coat of polyethylene on glazed imitation parchment is apparent from the observation that the oxygen permeability of the material when coated with PVDC at 25 g/m^2 on the paper side was appreciably higher than when a coating of 17 g/m^2 was applied over the polyethylene layer.

Recent studies have shown that the high oxygen permeabilities observed on this and other batches of glazed imitation parchment coated with PVDC are due to small discontinuities in the coatings.

Fabricated Packages

In practice, it is assumed that the oxygen permeability of a fabricated container is predictable from test-cell measurements made on flat specimens of the container material. However, the effect of heat seals and fabrication damage may influence the permeability of a made-up container, and these effects are not taken into account in measurements made by test-cell techniques. In an attempt to clarify these uncertainties, studies were made recently by Davis and Burns to develop methods to measure the oxygen permeability of flexible-film containers, and to compare results obtained by these methods with those observed on flat specimens of the same films by a test-cell method.

The results of these studies showed that test-cell values determined on a range of commonly used flexible films, excluding laminates based on paper and on aluminium foil, provide a close estimate of the oxygen permeability of packages hermetically sealed from the same films. As expected, packages constructed with leaky heat-seals were appreciably more permeable than those sealed hermetically. Determinations made on fabricated packages, however, should provide more reliable data on oxygen permeability than those made on flat specimens with materials that are highly susceptible to fabrication damage, such as waxed papers and some of the aluminium foil laminates.

Effect of Relative Humidity

The relative humidity (R.H.) of the test gas is known to influence the gas permeability of hydrophilic films, but it has no effect with hydrophobic materials (Simril and Hershberger 1950; Meyer *et al.* 1957). Davis (1964) has shown that regenerated cellulose films coated on both sides with nitrocellulose, or coated on one side with this material and on the other with polyethylene, were more than one thousand times more permeable to oxygen at 92% R.H. than at 0% R.H. Similar films coated with PVDC instead of nitrocellulose were more than 27 times more permeable at 92% R.H. than at 0% R.H.

The effect of R.H. is due to the sorption of moisture, which acts as a plasticizer for the film by lowering the cohesive forces and increasing the mobility of the molecules. The overall result is an increase in the diffusion constant which is reflected by an increase in gas permeability.

Similar increases in the gas permeability of films have been observed with other vapours that are readily sorbed by the films. For instance, the oxygen and nitrogen permeabilities of polyethylene are not affected by water vapour, but increase in the presence of n-hexane or carbon tetrachloride (Pilar 1960).

Flavour Studies on Salted Peanuts

Salted peanuts are representative of a class of foods that is sensitive to moisture and oxygen. Moisture uptake results in loss of texture, and oxygen affects flavour by inducing rancidity in the fatty components. Davis (1966) showed that the rate of texture loss in packaged salted peanuts is related to the water vapour permeability of the containers. The present work demonstrates the importance of the oxygen permeability properties of containers on the rate of flavour loss.

The test-pack experiments on salted peanuts were made with three replicate batches of Virginia kernels processed by a commercial processor. The raw kernels were dry-roasted, blanched, cooked in oil, salted (2% dry NaCl), and cooled in air. They were then packaged in pouches made from two types of flexible film and, as a control treatment, in tinplate cans (Table 2). The test packs were stored for 24 weeks at 25°C, 65% R.H., and examined at intervals for flavour by an analytical taste-test panel of 12 judges.

The judges were asked to score the samples on a scale from 10 to 0 in which 10 represented 'excellent' flavour, and 0 represented 'completely unacceptable' flavour. Further descriptive terms were included in the scale to indicate that the flavour of samples scored 6 or higher was 'satisfactory' but that scored 5 or lower was 'unsatisfactory'. The border line of acceptability could thus be defined by a mean panel score of 5·5, and the storage time necessary for each treatment score to reach this value defined the shelf life of the treatment.

Figure 2 shows the mean panel scores for flavour of salted peanuts packaged in three types of container during storage for 24 hours at 25°C, 65% R.H. Over the 24 weeks' storage period there was no statistically significant decrease in flavour of the kernels packaged in tinplate cans, but for two types of flexible-film container the flavour losses were significant. Kernels from the code X containers scored significantly higher for flavour than those from the code V containers over the 9–24 weeks' part of the storage period.

The calculated shelf lives, based on the storage times for the mean flavour score to reach 5·5, were 8·2 and 24 weeks respectively for the film containers coded V and X; the flavour of the kernels packaged in impermeable tinplate cans (T) was still satisfactory after the 24 weeks' storage period. These observed shelf lives are consistent with the oxygen permeability values determined on the container materials (Table 2); an increase in oxygen permeability corresponds to a decrease in shelf life.

These observations demonstrate that the oxygen permeability of the container is an important criterion to consider when selecting a container for retaining flavour in salted peanuts. Although these results were obtained with specific types of container material and with a specific food, similar principles apply to studies of the packaging requirements of other oxygen-sensitive foods. The shelf lives applicable to other foods, however, would be determined by the oxygen sensitivity of the foods as well as by the oxygen permeability of the containers in which they are packaged.

Table 2
Details of Test Packs of Salted Peanuts

Treatment Code	Container Material	Container Size	Fill-in Weight (oz)	Oxygen Permeability (cc(s.t.p.) × m^{-2} × 24 hr^{-1} × 76 cm^{-1}Hg at 25°C, 65% R.H.)
V	300 MSADT cellulose/ 0·001 in. polyethylene	30 in^2 between seals	1	67
X	300 MXDTA cellulose/0·001 in. polyethylene	30 in^2 between seals	1	8·0
T	Plain 1·25 lb/b.b. hot-dipped tinplate	202 × 214	3	—

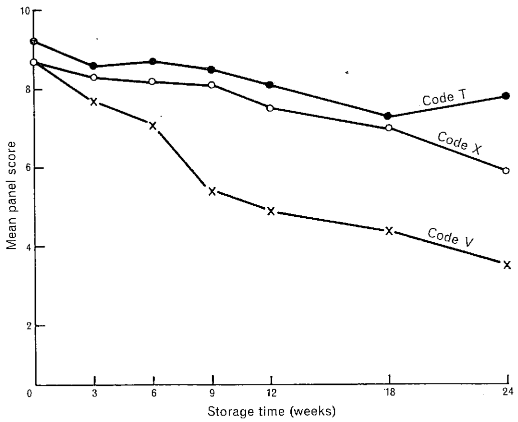

Fig. 2.—Changes in the mean panel score for flavour of salted peanuts during storage at 25°C, 65% R.H.

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Obituary

It is with deep regret that we record the death on April 28, 1968, of Dr. George Cunningham, who edited the *CSIRO Food Preservation Quarterly* for some years. Dr. Cunningham had been in ill health for a long time, though he courageously continued with his work to within a month of his death.

Born in Calcutta in June 1916, Dr. Cunningham received his early education in India and his university training at Leeds, where he graduated B.Sc. with first-class honours in chemistry in 1941 and took his Ph.D. in 1945.

Dr. Cunningham's speciality was leather science. After some years in the leather industry in England he accepted a post in the Leather Industry Research Institute at Grahamstown, South Africa, and lectured in leather science at the neighbouring Rhodes University.

Dr. Cunningham came to Australia in 1953 to assume the position of Deputy Director of the Australian Leather Research Association in Sydney, N.S.W. Later he became Director. In 1960 the leather industry closed its research laboratories, and Dr. Cunningham joined the CSIRO Division of Food Preservation to devote his considerable talents to the editing of scientific and technical publications.

Packaging Demonstrations

On March 21, 1968, the Division of Food Preservation in conjunction with the National Packaging Association of Australia gave a series of lectures and demonstrations at its research laboratories at North Ryde on technical aspects of packaging. Seventy-three members of the packaging industry attended, including nineteen from States other than New South Wales. The visitors were welcomed by Mr. M. V. Tracey, Chief of the Division of Food Preservation, and Mr. C. R. E. Warren, National President of the National Packaging Association of Australia.

The demonstrations were as follows:

Some effects of water movement in carton materials: Mr. J. Middlehurst.

The gas packing of fresh fruit: Mr. E. G. Hall and Dr. W. B. McGlasson.

The physical examination of flexible films: Mr. R. A. Burns.

The gas permeability of flexible films, and analysis of headspace gases in film containers: Mr. E. G. Davis.

Examination of packaging films under the electron microscope and infrared spectrophotometer: Dr. J. Bain and Dr. R. V. Holland.

Electrochemical techniques for examining tinplate: Mr. P. W. Board.

Technological Problems of

Meat Production and Export

By W. J. Scott

Meat Research Laboratory, Division of Food Preservation, CSIRO, Cannon Hill, Qld.

In this paper the author, who is Officer-in-Charge of the CSIRO Meat Research Laboratory, discusses the technological problems of an industry that earns a great deal of export income for Australia and New Zealand. The paper was a contribution to a symposium on food production at the meeting of the Australian and New Zealand Association for the Advancement of Science held in Christchurch, New Zealand, January 1968.

IT is a privilege to have this opportunity of contributing to this symposium on the processing and utilization of food, a subject which will prove to be of increasing importance to all of us in the future. We must, I believe, look to modern technology to help us achieve more efficient use of food actually produced, by prevention of waste and by the development of new products that combine high nutritive value and palatability with continuous availability. These things need to be done at cost levels that will not inhibit consumption.

For my particular subject, meat, it is especially fitting that we should be meeting here on the Canterbury plains, a region which has given its name to the celebrated Canterbury lamb.

Production and Consumption

Let us look for a moment at the Australian and New Zealand contributions to world meat production. Of the total annual world production of some 50 million tons, our two countries together account for about 5%. We are also both prodigious consumers, with annual consumptions per head some 7–8 times the world average of about 30 lb. None the less, we have an export surplus approaching half of our combined production, and this surplus accounts for about 30% of the meat entering into world trade. Figure 1 shows recent trends in production and consumption for each country. The New Zealand figures, reflecting more uniform seasonal conditions, are less variable than the figures for Australia. Australian exports account for about one-third of production whereas in New Zealand about two-thirds of production is exported. Both countries have substantial exports of beef and mutton. Australians, however, eat some 40 lb of lamb per head each year and so consume over 90% of their country's production. In New Zealand you appear to find lamb less acceptable, for you consume only 18 lb per head—less than 10% of your production.

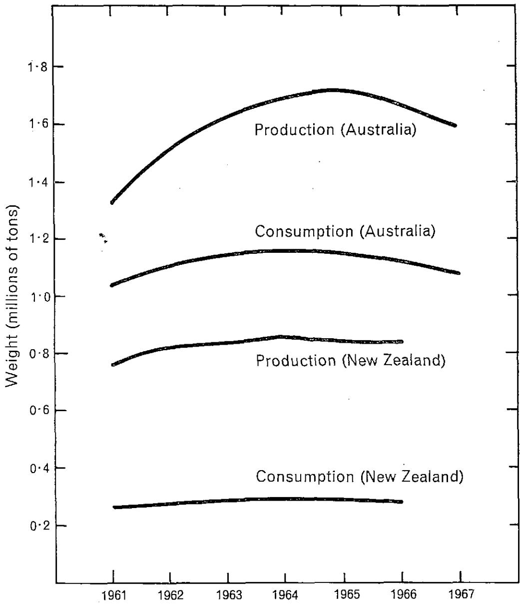

Fig. 1.—Annual production and consumption of meat in Australia and New Zealand.

The aggregate annual value of meat exports from Australia and New Zealand exceeds 500 million dollars.

Composition of Carcass Meats

It is appropriate, therefore, to consider the approximate composition of the goods we are selling on the world's markets. Almost all Australian exports are now in the form of boneless meat, frozen in cartons. For most of this trade, specified fat contents would not exceed 15–20 %, the balance being lean meat comprising about one-quarter protein and three-quarters water. Boneless meats containing 20 % fat will have, therefore, about one-half of their dry matter as fat and one-half as protein. It has long been known, however, that in carcass meats the ratio of fat to dry protein is frequently greater than 1. Lawes and Gilbert (1859) showed that values greater than 2 were frequently observed and that in a very fat sheep the ratio exceeded 6. For fat lambs nowadays the ratio is between 2 and 4 and is independent of the side of the Tasman on which they are produced (Kemp and Barton 1966; Kirton, Barton, and Rae 1962).

Figures 2 and 3 summarize regressions of muscle weight on body weight and of weight of fat on body weight for sheep, pigs, and cattle. For muscle the regression coefficient is close to unity, showing that muscle remains a substantially constant fraction as body weight increases. The larger coefficient for fat emphasizes that meat animals, like ourselves, become fatter as they mature. The present world market price for lean meat is about 4–5 times that for tallow and there are, therefore, severe economic penalties for removing from carcass meats fat which is in excess of market needs. Moreover, it should not be overlooked that the energy content of fat is about nine times the energy content of an equal weight of fat-free muscle. A major technological problem for producers and scientists is to develop animals and husbandry practices that will increase the yield of lean meat. Substantial progress has been made in recent years in increasing the efficiency with which poultry convert feed to meat. Some improvements in the performance of pigs have also been achieved, but with ruminants there is little progress to report. Increasing the muscle-synthesizing performance of our meat animals is undoubtedly a major problem for both Australia and New Zealand.

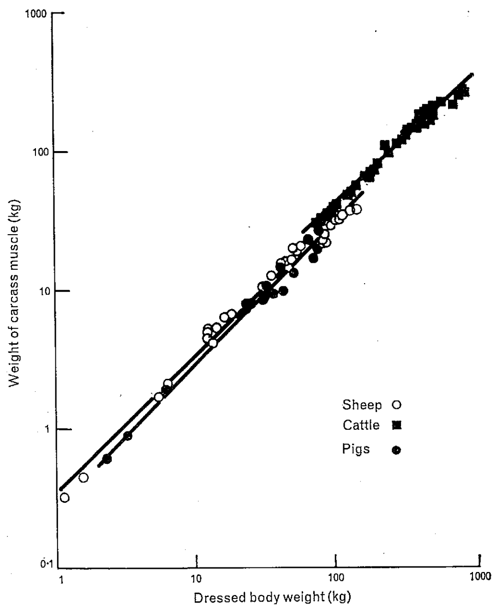

Fig. 2.—Regression of carcass muscle on body weight (from Tulloh 1964).

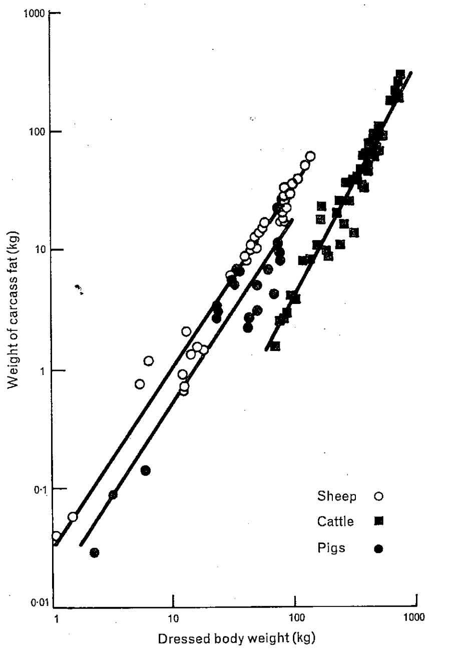

Fig. 3.—Regression of carcass fat on body weight (from Tulloh 1964).

Handling and Transport of Animals

Inevitably animals must be transported from farms to points of slaughter, even though the distances and times may amount to only a few miles and a few hours. Under some circumstances in northern Australia cattle may be transported for many hundreds of miles, and animals may be held for periods of a week in vehicles and yards with only limited access to food and water. Several consequences of animal transport have been recognized and are discussed below.

Yield of Carcass Meats

During the first 24 hours of transport there is little effect on carcass weight although Kirton *et al.* (1965) have shown that lamb carcasses may lose weight after periods as short as 14 hours. For adult cattle, daily losses during starvation have been assessed at 0·8% per day (Shorthose 1965). For lambs Kirton *et al.* (1965) reported a high rate of about 1 lb (or 3%) per day. The chemical nature of the substances lost has not been established.

Properties of Meat

It has been known for a long time that the rate and extent at which muscle glycogen is converted to lactic acid after death have a marked effect on the properties of the muscle. In pigs especially, muscle glycogen levels are readily depleted by exercise and during transport, and a higher ultimate pH results. Certain breeds of pigs are prone to develop pale watery pork, a condition due to accelerated glycolysis which causes some of the soluble muscle proteins to be denatured by a combination of low pH and high temperature (Briskey 1964). It appears that brief periods of intense exercise immediately before death, such as fighting or struggling, lead to a marked acceleration of glycolysis, and hence the pale watery appearance develops during the onset of rigor. More sustained exercise depletes the glycogen and the muscle remains dark with an ultimate pH over 6·0. There is little evidence that pale watery pork has been troublesome in Australia even where Landrace pigs have been introduced.

Exercise has much less effect on glycogen levels in bovine muscle. Holding cattle under some conditions (not as yet precisely defined) does lead to substantial depletion of glycogen, resulting in 'dark-cutting' beef and a high ultimate pH. Dark-cutting beef has occurred but its incidence has been mainly sporadic.

Much research is still needed to establish the relative importance of the various stresses to which animals are subjected during transport and marketing before appropriate corrective measures can be taken. At present it is sufficient to note that after travelling long distances animals may need feeding and resting for several days if they are to regain their 'normal' physiological state.

Microbiology of the Meat

As might be expected, crowding together of susceptible animals brings increased risks of acquiring acute infections from contaminated environments in vehicles and yards. Increasing the holding time increases opportunities for cross infection and several outbreaks of enteric disease have been reported, especially in pigs and calves. Adult ruminants are less susceptible.

Recently Grau and Brownlie (1965) and Brownlie and Grau (1967) studied the intestinal microflora of healthy cattle and sheep at slaughter in several Australian meatworks, and found the incidence of *Salmonella* spp. in the rumen and in faeces to be higher there than on farms. They found that starvation and interrupted feeding led to substantial growth of salmonellae and coliform bacteria in the alimentary tract. Under some circumstances there was also an increased incidence of these organisms on the meat. The high number of enteric organisms in the alimentary tract of some animals increases the need for very great care if contamination of the meat is to be avoided. Because of the shorter distances involved in the transport of livestock in New Zealand, the problem may well prove to be less important here than in Australia. None the less, the very large numbers of lambs and calves which are transported provide opportunities for pathogens to develop and spread in these susceptible animals.

It should be noted that there may be difficulties in providing conditions for resting and feeding of transported animals that will prevent the spread or development of infections. This is particularly true in northern Australia, where cattle from inland tick-free areas are moved to meat-works in coastal regions: these animals soon acquire ticks carrying the protozoan parasites that cause tick fever, to which they are completely susceptible.

Preparation and Processing

It would not be appropriate in a talk of this nature to attempt a detailed consideration of the many different processes involved in the preparation and processing of carcass meats. It may be useful, however, to mention some of the trends apparent in recent years.

Stunning.—There is a need for improved humane stunning procedures which will avoid certain defects such as haemorrhages in the muscle and variable post-slaughter biochemical changes in the meat. Electrical stunning has been widely used, especially for pigs and, to a lesser extent, for sheep. The process is more efficient when the animals are conveyed mechanically and the operator has full control over the position of the animal when the electrodes are applied. A further improvement, in which the electrodes are inserted automatically, is said to have been developed in Denmark. Carbon dioxide anaesthesia, which has been widely used for pigs, would also be suitable for sheep if the extravagant absorption of gas by the fleece could be avoided.

Skinning.—At present, skinning involves a great deal of hand labour, but some progress in mechanization has been made in recent years. Skinning of calves is now partly mechanized in many works in Australia and New Zealand, but suitable equipment for sheep and lambs is not yet available. Skinning of cattle is now beginning to be partly mechanized and Russian engineers are reported to have developed satisfactory devices for this operation.

Washing.—Procedures for the removal of visible soiling and microbial contamination by washing are at present of limited efficiency. It would be helpful if residual microorganisms could be removed more decisively, and a process for destroying any pathogens embedded in the surface tissues would be of great value. A terminal process in which carcasses are immersed in hot water may need to be developed.

Cooling.—Carcasses are usually cooled in special chill rooms to which they are transferred immediately from the slaughter floors. Investigations at the Meat Industry Research Institute of New Zealand have shown, however, that very rapid and immediate cooling leads to some loss of eating quality. A conditioning process is therefore being developed, in which the lamb carcasses are held for several hours at temperatures of about 15°C before chilling. This allows rigor mortis to proceed to completion before the carcass is cooled, and the resulting meat is more tender. When carcasses are cooled in moving air there is an associated evaporation from the meat surface. This superficial drying is useful for the control of microbial development if the meat is subsequently to be stored and distributed in the chilled condition. It is, however, not essential when the meat is subsequently preserved by freezing. The geometry of carcass meats imposes certain limitations on the rates of cooling that can be achieved. When high rates of heat transfer are obtained at meat surfaces, the rate of heat conduction through the meat soon becomes limiting. For this reason it is not possible to cool the centre of beef sides to less than about 10°C in 24 hours when the sides are hung in rapidly moving air at the temperature of the freezing point of meat, namely about −1°C. Hydro-cooling has been used for poultry meats and this process leads to fairly rapid uptake of water. For chickens, weight gains up to 8% are now permitted in the U.S.

Boning.—As with skinning, boning of carcass meats requires large amounts of hand labour. Ordinarily the process is carried out after cooling of the carcass or side. Mechanization would be a desirable development, and this would probably be facilitated if the meat were removed from the skeleton while the tissues were still warm and in the pre-rigor condition. When muscles are removed from their skeletal attachments they are, of course, free to contract; substantial contraction would therefore be likely when this is done in the pre-rigor condition, and meat so treated may become excessively tough. On the other hand, for certain manufacturing purposes, pre-rigor meat is reported to be advantageous and to have superior emulsifying and water-holding properties. Some patents have been granted for the use of pre-rigor meat in sausage manufacture. Processes that would substantially inhibit the onset of rigor would be very useful in this connection. The addition of salt to meat while it is still in the pre-rigor condition permits retention of some of the pre-rigor properties after freezing.

Freezing.—During recent years there has been a tendency for freezing to be accomplished in high-velocity air. The advantages are economic rather than technical, the principal object being to reduce the capital requirements for freezing a given quantity of meat. There is no evidence that within the range commercially obtainable, variations in the rate of freezing would have any important effects on the properties of the meat after freezing and thawing.

Storage Temperatures.—The temperature of storage has important effects on the rate of deterioration during storage. A significant development of undesirable flavours may occur in frozen meats within 3 to 6 months at $-10°C$. At $-20°C$ the rates of deterioration are reduced by a factor of about 4.

Tenderness and Appearance

One of the principal defects of fresh meats for roasting or grilling is lack of tenderness. The substantial variations in mechanical properties between different parts of the same carcass and between the same kind of muscles in different carcasses are, at present, poorly understood. This variability constitutes a considerable barrier to the acceptability of meat in some markets. Tenderness can be substantially improved as the result of certain rather ill-defined degradative changes promoted by endogenous enzymes. Thus holding fresh meat for about 2 weeks at temperatures of 0–2°C, or for shorter times at higher temperatures, brings about a sufficient change in tenderness.

Tenderizing with exogenous enzymes has also been used. As the concentration of enzyme required for the best effects is somewhat critical, it has been difficult to achieve substantially uniform distribution of enzyme throughout that portion of the carcass selected for tenderizing. Improved methods for injection have been suggested, but further modifications are needed.

In recent years there has been a great increase in the retail sale of fresh meats packaged in flexible films. The films used have been permeable to oxygen, as this retains the bright red colour of the meat. With these aerobic conditions and high humidities within the package, rates of deterioration by microorganisms are high. Accordingly, shelf life is limited to a very few days, and there is clearly a need for improved packaging that would extend the shelf life of the product. Film which would also reduce photochemical degradation of the meat pigments would be very helpful.

Utilization and Marketing

Some opportunities exist for utilizing a greater fraction of the animal tissues for human food. There are at present some aesthetic barriers which assert that certain tissues are inedible. For example, fat from some organs is described as inedible tallow. Modern technology can, however, make such fat chemically indistinguishable from fat from other sources, and the regulations may need to be modified to recognize this fact. Another example is protein from blood. In some countries blood protein is acceptable as human food, whereas in others it is regarded as inedible. Present slaughterings in Australia and New Zealand release each year about 100,000 tons of blood from which some 15,000 tons of first-class animal protein could be obtained. The problem is to collect the blood and separate the protein at an economic price.

Market outlets and the form in which meat is marketed are changing rapidly in many countries. As mentioned above, an increasing fraction of fresh meat sales is prepackaged. In the United States, trade sources have reported that at least 70% of all retail sales of meat in 1966 were through chain stores, as compared with only about 5% through individual butchers' shops. The balance of sales was directly to hotels, restaurants, hospitals, and various institutions. There has been a rapid increase in the manufacture and sale of meat as sausage and other cooked ready-to-eat products.

The increase in sausage production in Japan has been spectacular. Meat handling and processing have to an increasing extent become the business of large companies with a large turnover. They generally exercise close quality control and have a policy of marketing under brand names designed to retain old customers and to obtain new ones. In these companies there has been increased attention to uniformity, to securing freedom from faults in flavour and texture, and to obtaining improved shelf life. Manufacturers achieve these objectives in various ways. One contribution is by large-scale operations and the use of mixing and blending which assists in overcoming variability between and within carcasses. Specifications on raw materials and processes are becoming more precise and may well extend to areas not at present covered.

There is, in America especially, a move to achieve greater mechanization and automation with very close control over raw materials, processing conditions, and packaging designed to protect the product and ensure a shelf life adequate to reach large nation-wide markets. The original geometry of the carcass, the roast, steak, or chop, has frequently disappeared and oval-shaped slices of ham are now fabricated from the forequarters of the pig as well as from the hindquarters.

An example of American developments in meat technology is a modern continuous process for the manufacture and packaging of wieners. Conceivably its raw materials include American pork and, let us say, Australian beef and New Zealand mutton. It is an integrated processing and packaging system designed to minimize all sources of variation. Initially a computer determines the most economical formulation which will attain the required specification from information on the cost and chemical composition of the raw materials on hand. After mixing in large batches, sampling, blending, heating, further comminution, and deaeration, the emulsion is metered into 100-ft-long casings moving at carefully synchronized rates. These casings ensure uniform geometry for subsequent smoking, cooking, and cooling, after which they are automatically removed. Individual sausages with a high degree of uniformity are then packaged automatically in vacuum-sealed film. The absence of people and the continuous sanitation of the equipment effectively prevent recontamination after cooking. A greatly increased shelf life results.

We have seen then that the technological problems of our meat industry reside in four main areas, of which the first two concern the live animal. Firstly we must learn how to increase the production of meat and maximize the monetary returns to producers. At present this objective would appear to be met by systems which will give the greatest production of lean meat per acre. The second general area covers the problems of preventing undesirable changes in meat animals during transport and marketing. The third area is concerned with the conversion of meat animals into carcass meats. Here we have many operations and there are consequently numerous opportunities for improving efficiency. Finally, there is the need to develop procedures which will result in improved utilization of the edible tissues and which will yield products with satisfactory levels of palatability, nutritive value, and stability. If we are to become more efficient we must improve our specifications of the meat we want and see that these are regularly communicated to producers, who will then have an incentive to meet the market needs. When suitable meat animals have been produced, the uniform attainment of our various goals will depend on the combined contributions of all who are subsequently associated with the preparation, processing, and distribution of all the forms in which meat is marketed.

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Developments in

Low-temperature Evaporation

By D. J. Casimir and J. F. Kefford

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Concentrated foods are appearing in food markets in greater variety and improved quality because of advances in the design of equipment for evaporating water from foods. This article is based on a talk by Mr. J. F. Kefford at the First Annual Convention of the Australian Institute of Food Science and Technology, Shepparton, April 1967.

MOST liquid foods consist mostly of water, and for reasons of economy in packaging, storage, and transport, or of microbial stability, the food technologist often seeks to remove some of this water. His aim is to obtain a product, a *concentrate*, from which the original food, unchanged in quality and nutritive value, can be reconstituted simply by adding water.

This naive aim is seldom achieved, because the removal of water is accompanied by changes in the food that cannot be completely reversed by the replacement of water. These irreversible changes may take place in two ways: the concentration process may remove other volatiles as well as water, and there may be chemical changes in the residual concentrate.

Water may be removed from foods as vapour by evaporation, as ice by freezing concentration, and as liquid water by membrane concentration techniques. The present discussion is restricted to concentration of liquid foods by evaporation, and specifically to low-temperature evaporation, by which is understood evaporation under vacuum at temperatures below the boiling point at atmospheric pressure. In pursuit of the basic aim of minimizing irreversible changes in quality, the food technologist specifies evaporation with the minimum possible total heat treatment (Kefford 1954).

At this stage the problem becomes one for the food engineer who is assigned the task of designing a piece of equipment to concentrate a specific product. A number of requirements may be laid down, but only some of these are amenable to quantitative specification, thus:

- Capacity, usually expressed as lb of water evaporated per hour.
- Level of concentration, to a specified solids content.
- Acceptable level of heat damage, related to product temperature and residence time.
- Recovery of volatiles may or may not be required.
- Microbiological hygiene, ease of cleaning, and freedom from fouling ('burn-on').
- Economy in capital and operating costs, related to lb water evaporated per sq ft of heat transfer surface per hr, and lb of water evaporated per lb of steam consumed.
- Ease of operation and control.
- Space requirements, related to available floor area and height.

In fact, the design of evaporators is one of the most difficult tasks to put before a food engineer. It involves problems of fluid transport, heat transfer, and mass transfer under reduced pressure. The engineering problems combined with the requirements of product quality and hygiene defy precise solution. Generally speaking, therefore, the approach to evaporator design has been a composite one, based on background theory, pilot-plant experience, intuitive judgment, and imagination.

Basically an evaporator consists of a heat exchanger to supply the sensible heat to raise the product to its boiling point and also the latent heat of vaporization, and a condenser to remove the resultant vapour. Between these units there is interposed a device to separate the vapour from the concentrate. Usually it is a cylinder into which the vapour enters tangentially and is discharged at the centre so that entrained droplets are precipitated by centrifugal action. There must be provision for removing the concentrate and the condensate by means of barometric legs or pumps. Then at the end of the line is a source of vacuum, usually a steam ejector, to maintain a low pressure and to remove non-condensable gases. It is also possible to separate volatiles from the condensate; sometimes adding back the volatiles to the concentrate is desirable, sometimes undesirable. This is a subject in itself and not of immediate interest in Australia, so it will not be enlarged upon here.

Heat Exchanger

It is in the heat exchanger that the principal design problems arise and the quality of the food is most affected.

The simplest form of vacuum evaporator is the vacuum pan in which heat is supplied to a large mass of product from a steam jacket, a coil, or a calandria. The residence time is prolonged and the product is subjected to the risk of severe heat damage. Progress from this primary method is represented firstly by continuous instead of batch operation, and secondly by improved rates of heat transfer, achieved by moving the product over the heat transfer surface as a thin film at high velocity with turbulent flow.

WURLING Evaporator.—One way of doing this is to move the heat transfer surface through the product, for instance by using a rotating steam coil. This principle is well known in evaporation practice at atmospheric pressure and it has recently been applied to vacuum evaporation by engineers at the Western Utilization Research Branch of the U.S.D.A. (Carlson *et al.* 1967). They have coined the name WURLING evaporator for their rotating steam coil device, which has been designed particularly for the production of tomato paste. The rotating coil is totally submerged in a hemi-cylindrical pan and it moves through the product with a peripheral velocity of 5–20 ft/sec. Since a minimum of vapour is formed in the liquid the danger of burning on is substantially reduced. When the evaporator was operated continuously for 2 days in pilot runs concentrating tomato paste from 20% to 50% solids no fouling occurred and the product is claimed to have had a very good colour. In this type of evaporator, however, the hold-up of product in the evaporator is large and consequently there is a long residence time. These factors are less important with tomato products than with more heat-sensitive foods. Compared with agitated-film evaporators, the WURLING evaporator is claimed to be cheaper to build while in performance it achieved a better evaporation rate with cold-break tomato pulp, although not as good with hot-break tomato pulp.

In the WURLING evaporator a thin turbulent film of product is created on a moving heated surface. The more usual way of achieving rapid heat transfer is by moving a thin film of the product over a stationary heating surface. To achieve required capacities the heating surface is increased in area by forming it in the shape of tubes (Moore and Hesler 1963), plates (Anon. 1966*a*, 1966*b*), or cones (Shinn 1965).

One of the chief difficulties in evaporator design is to ensure satisfactory distribution of the product over the heat transfer surface. If any portion of this surface remains unwetted, optimum use is not being made of the available heat transfer surface and, in addition, local overheating of the product may occur to the detriment of quality and with a likelihood of burning on. Spreading of the film of product on the heat transfer surface may be accomplished with the assistance of the vapour produced when boiling occurs, or the film may be spread mechanically.

Rising- and Falling-film Evaporators.—Evaporators in which the spreading of the film is vapour-induced include the types to which are given such names as rising-film and falling-film evaporators (Kefford 1954). In a rising-film design, the product is fed to the bottom of the heat exchanger and rises during evaporation. Good distribution over the heat transfer surface is achieved but extraction of the product is not easy, and the temperature difference between heating medium and product must be relatively high to overcome the hydrostatic head and maintain circulation. In a falling-film design, on the other hand, extraction of the product is facilitated, but problems of distribution over the heat transfer surface may be encountered. It is not generally satisfactory to rely on gravity flow alone, so the product is flashed into the header and driven down the heat exchange tubes by vapour.

To some extent the virtues of evaporators based on rising and falling films can be combined, and the disadvantages minimized, by designing an evaporator which incorporates, in successive sections of the heat exchanger, both rising and falling films. Figure 1 shows a plate evaporator that operates with rising and falling films of product (Anon. 1966*a*).

Another design decision that must be made is whether to rely on a single pass or to incorporate recirculation of the product. In general, evaporators using recirculation are falling from favour owing to the long residence times encountered, whereas single-pass evaporators are gaining popularity. For example, in the concentration of orange juice, recirculating falling-film evaporators operating with a maximum temperature of 75°F have been replaced by multiple-effect evaporators based on high-velocity single-pass principles. A superior product is obtained even though the evaporation temperature is about 130°F.

Mechanically Agitated Evaporators.—The problems of achieving satisfactory product distribution and of maintaining adequate rates of heat transfer are intensified in the evaporation of highly viscous products, and those containing suspended solids. Here the application of a mechanical method for spreading a thin film of product on the heat transfer surface has major advantages. Evaporators of this type include several in which a thin film of product is spread by an internal rotor. Rotors may have a fixed clearance of 0·01–0·03 in., or fixed blades with adjustable clearance, or blades which actually wipe the heat exchange surface and which are spring-loaded or held out by centrifugal force (Moore and Hesler 1963; Mutzenburg, Parker, and Fischer 1965). Where the design includes small clearances, expensive machining operations are involved and may lead to high initial capital cost. Conversely, where the blades wipe the surface, larger heat transfer surfaces are possible because the machining need not be as accurate as with fixed blades.

The rotor blades, with peripheral speeds up to 40 ft/sec, push ahead of them a highly turbulent 'bow wave'. The material in the bow wave then enters a 'squeeze or clearance zone' of high turbulence between the rotor and the heat transfer surface, which is followed by a 'tranquillizing zone' prior to the arrival of the next bow wave. The power requirement for driving the rotor is often high, especially when evaporating products of high viscosity, and the power is mainly consumed in overcoming internal friction within the liquid. The high rates of shear that are encountered decrease the viscosity of thixotropic materials, such as tomato products, and so assist to maintain high heat transfer rates. A pilot-scale mechanically agitated film evaporator is shown in Figure 1.

Centrifugal Evaporator.—In a further recent development in evaporator design the film of product is spread centrifugally on a moving heated surface (Shinn 1965). The heat transfer surfaces of the centrifugal evaporator are rotating truncated cones: the inside surface is the product side, and the outside surface the steam side. A feed tube distributes the liquid onto the innermost part of the conical surface where it spreads under the influence of centrifugal force, forming a thin film as it moves towards the periphery at the lower edge of the cone. A film thickness of 0·004 in. and a contact time of 0·5–2·0 sec on the heat transfer surface are claimed for low-viscosity liquids, while the measured mean residence times including hold-up in feeding and discharge are 10–20 sec (Mälkki and Veldstra 1967).

A high rate of heat transfer is also assisted by dropwise steam condensation, which takes place on the steam side of the revolving cone because the film of condensate normally associated with stationary steam-heated heat transfer surfaces is removed by centrifugal force. A pilot-scale centrifugal evaporator is shown in Figure 1.

Vacuum-spray Evaporation.—Future progress in evaporator design may lie in the direction of eliminating entirely the heat transfer surface. Vacuum-spray evaporation, another development emanating from the Western Utilization Research Branch of the U.S.D.A. (Anon. 1965), is a move in this direction. The workers who developed this process were seeking a method to remove 75% or more of the water from liquid foods in less than 1 sec with a product temperature not exceeding 100°F. They substantially achieved their object by spraying droplets into superheated steam at 700°F. The mean residence time in the vacuum-spray evaporator is only 0·2 sec but if recycling is necessary the residence time becomes 1 sec. This technique exposes as much of the product surface as possible to the heat source, and in addition fouling is eliminated since there is no heat transfer surface on which it can occur. For direct contact heating, superheated steam has two advantages over hot air: it is non-oxidizing and thus avoids detrimental effects on colour and flavour, and in addition the rate of heat transfer between water droplets and superheated steam is roughly twice as great as between the droplets and heated air.

Assessment of Evaporator Performance

How well do the evaporators available to food manufacturers measure up to the requirements specified? The most critical of these requirements is minimum heat damage. Present knowledge is inadequate for the proper assessment of heat damage to foods. What we need is a body of knowledge such as we have about thermal destruction of micro-organisms; that is, information on the integrated effects of the time–temperature treatment of foods on quality factors. But this knowledge does not exist so we are forced to fall back on certain empirical approaches.

Table 1
Residence Times in Evaporators

Evaporator Type	Av. Residence Time (min)	
	Calc.*	Measured†
Recirculating		
Calandria‡	53·8	170
Forced circulation, falling film‡	41·3	130
Rising film, natural circulation‡	23·1	95
Single-pass		
Mechanical agitated film‡	1·8	45
Rising–falling film, tubular‡	0·9	40
Rising–falling film, plate§	0·33	—
Centrifugal (100 l/hr without evaporation)‖	0·11	—

* Hold-up volume/average rate of discharge.

† Time for 97% replacement of methylene blue tracer.

‡ Data from Moore and Hesler (1963), evaporators operated under identical conditions.

§ Data from Meffert (1964).

‖ Private communication.

The time–temperature history of a product in a particular evaporator may be calculated. Under ideal conditions in a single-pass evaporator with plug flow, residence time is given by:

$$\frac{\text{Hold-up volume}}{\text{Volumetric flow rate of discharge}}.$$

In practice, ideal conditions of flow are never achieved because of such factors as channelling, local recycling, and the occurrence of stagnant pockets away from the main flow path. Residence times are also influenced by the effect of increasing concentration and viscosity on the flow rate. Direct measurements of residence time are therefore more reliable.

One method of measurement is by the use of tracers, such as dyes, electrolytes, or radioactive tracers, e.g. Moore and Hesler (1963) used methylene blue as a tracer and followed its movement through various evaporators colorimetrically. Their results, summarized in Table 1, show the residence times for 97% replacement of the tracer in particular evaporators in comparison with the average residence times calculated by dividing the hold-up volume by the discharge rate.

Another procedure for assessment of evaporator performance is to regard the evaporator as a chemical reactor and to follow the course of a chemical reaction which is influenced by the time–temperature history. A Dutch worker, Meffert (1964), has investigated this approach. He considered first the reaction producing hydroxymethylfurfural, which is a by-product of the degradation of sugars and is likely to be formed during evaporation of fruit juices if overheating occurs. But this was a difficult reaction to follow so he chose instead the inversion of sucrose. By evaporating sugar solutions under controlled conditions of temperature and pH in different evaporators and measuring the inversion, the average residence times may be calculated and compared. It should be remembered, however, that the kinetics of reactions causing heat damage to quality may be different from the first-order kinetics of the inversion of sucrose in dilute solution.

A third method of assessing the relative performance of evaporators is by direct comparison of the effects on the quality of a specific food. Opportunity for this type of

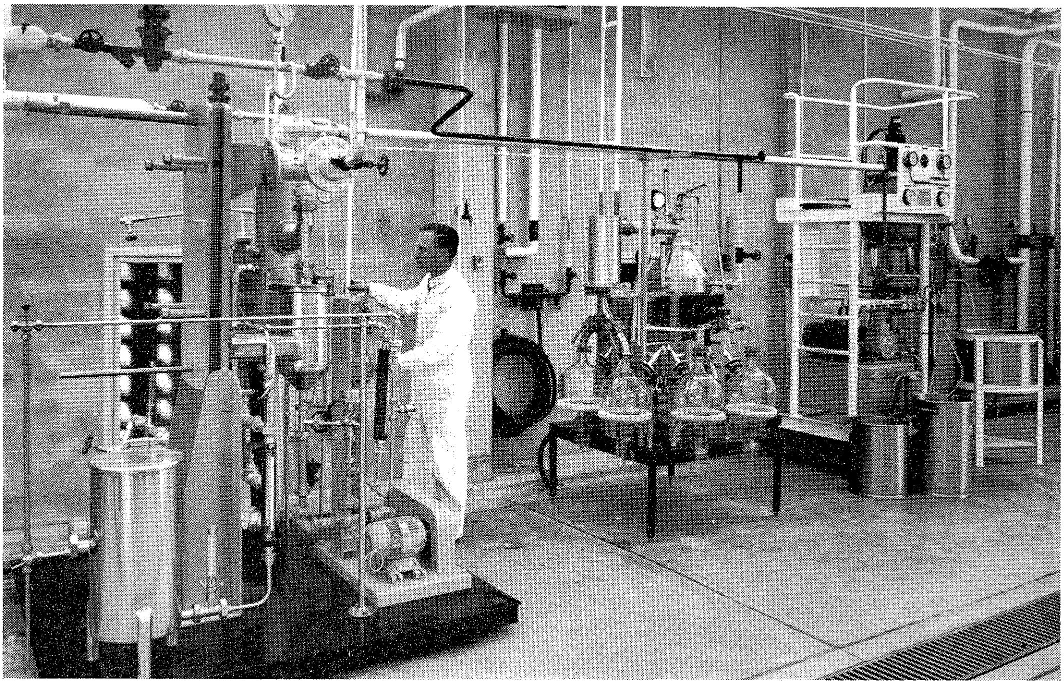

Fig. 1.—Pilot-scale evaporators in the Food Processing Laboratory, Division of Food Preservation, CSIRO Ryde. *Left*, plate evaporator; *centre*, centrifugal evaporator; *right*, mechanically agitated film evaporator.

comparison is limited because a range of evaporators is not often available for testing, and also because facilities for sensory testing are required.

Evaporator Trials

During the 1967 citrus season two comparative trials of this kind were made using orange juice as the test product.

In the first trial, pilot models of a plate evaporator and a centrifugal evaporator (Fig. 1) were compared in the Division's Food Processing Laboratory. Orange juice concentrate was prepared in both of these evaporators from two batches of Valencia oranges, one from Gosford, N.S.W., and the other from Berri, S.A. Two passes were necessary in the plate evaporator to reach the required levels of concentration. The reconstituted juices were then submitted to a panel of tasters, and the results are shown in Table 2.

In a triangle test the tasters readily found a difference between the concentrates from the two evaporators. The concentrate from the centrifugal evaporator was significantly preferred in each case, and was also considered to be closest to fresh juice in flavour. These results demonstrate the favourable effect of short residence time since the extent of heat damage to quality was greater in a double pass in the plate evaporator than in a single pass in the centrifugal evaporator.

In a second trial it was possible to compare the performance of three commercial evaporators which were located in adjoining plants. Details of the three evaporators follow:

A—A centrifugal evaporator in which the rotating conical heat transfer surface had an area of 25·4 sq ft and the capacity claimed was 1800 lb of water evaporated per hr.

B—A mechanically agitated evaporator with a fixed blade at a close clearance. The heat transfer surface had an area of 16·2 sq ft and the evaporating capacity was stated to be 550 lb of water per hr.

C—A forced-circulation tubular evaporator with a vertical rising calandria. No details of heat transfer surface area or water evaporating capacity were available.

The evaporators were fed with pasteurized orange juice from the same bulk batch and a sample of this juice was frozen and held at 0°F for subsequent comparative tasting.

The conditions during evaporation are set out in Table 3. After evaporation the concentrates were reconstituted to 8·9° Brix and submitted to tasting by a panel of 32 judges using a paired comparison design with four samples including the frozen pasteurized single-strength juice. The tasters were asked 'Which is the closest to fresh orange juice?' and 'Are the samples commercially acceptable?'. The results of the tasting tests are incorporated in Table 3.

The difference between the ratings for the reconstituted juices from evaporators A and B was not significant, but it is interesting to note that both of these juices were judged to be closer to fresh juice than both the reconstituted juice from evaporator C and the pasteurized single-strength juice held 14 days at 0°F.

Again it appears that the order of decreasing quality in the concentrates is the probable order of increasing retention time in the evaporators. The further observation that the quality apparently improves with increasing product temperature (vapour–liquid separator temperature) underlines the fact that it is not maximum product temperature alone but the total integrated effect of heating in the evaporator that determines the quality of the concentrate.

Table 2
Comparison of Concentrated Orange Juice from Pilot-scale Plate and Centrifugal Evaporators

	Fruit from Gosford, N.S.W.		Fruit from Berri, S.A.	
	Plate	Centrifugal	Plate	Centrifugal
Strength of juice				
Concentrate (°Brix)	53	49	65	69
Reconstituted juice (°Brix)	10·5	10·5	11·0	11·0
Triangle Test†				
No. correct	26***		20**	
No. incorrect	9		12	
No difference	2		5	
Preference test‡				
No. giving 1st preference	0	26***	4	16**
Closeness to fresh juice				
No. giving 1st preference	0	26***	3	27**

Significance: $^{**}P<0 \cdot 01$, $^{***}P<0 \cdot 001$.

† The taste panel comprised 37 judges.

‡ For judges who were correct in the triangle test.

Table 3
Comparison of Performance of Commercial Evaporators

Evaporator	A	B	C	
Flow within evaporator	Single pass	Single pass	Forced recirculation	
Feed (orange juice)				
Soluble solids (°Brix)	8·9	8·9	8·9	
Temp. (°F)	96	96	96	
Heating steam (°F)	199	214	223	
Vacuum (inHg)	25·6	27·5	28·8	
Vapour–liquid separator temp. (°F)	129	108	86	
Concentrate				
Soluble solids (°Brix)	43·8	45·4	44·6	
Discharge temp. (°F)	91	95	90	
Tasting tests	Concentrated juices reconstituted			Frozen juice
Order of closeness to fresh juice	1	2	4	3
Acceptability (% Yes)	96	93	71	82

Economy

While the food technologist may consider product quality to be the most important attribute in an evaporator, it is likely that management will be most interested in economy.

It is not difficult to design an evaporator in which 1 lb of water is evaporated by 1 lb of steam, or say 1·1–1·2 lb of steam to allow for losses. One way to obtain better steam economy is by multiple-effect evaporation. Most of the heat applied in evaporation is absorbed as heat of vaporization and accordingly is retained in the water vapour from the product. This vapour may then be used for heating the product in a second effect, and so on. The pressure is successively lower in the subsequent effects to lower the boiling point. Between effects the vapour may be recompressed by a steam booster to raise its temperature. Usually the feed is 'backwards' so that concentration is completed at the highest temperature, that is when the viscosity and boiling point are highest.

In general terms, multiple effects will decrease steam consumption per lb of water evaporated in the ratio $1/n$ where n is the number of effects. But the capacity remains the same as in a single-effect evaporator operating under the same initial and terminal conditions. This means that the heat exchange surface is increased to improve steam economy, but without increasing capacity. Residence time, moreover, is also increased and quality may suffer.

Choosing an Evaporator

How does an Australian food processor select an evaporator? We do not believe that there is a universal general-purpose evaporator that will handle all foods. Therefore the answer to this question must be qualified in terms of products. Then for a particular product there must be a balance between product quality, capital cost, and operating costs. In a paper such as this only generalized advice can be given:

- Multiple effects reduce operating costs but increase capital costs and prolong residence time.
- Mechanically agitated evaporators cost more per unit area of heat transfer surface, but this is largely offset by higher overall heat transfer coefficients, which permit a reduction in the size of the heat transfer surface.
- Product quality is highest where residence time is shortest.

Looking now at some particular products:

- Tomato pulp becomes highly viscous and thixotropic at fairly low concentrations but is less sensitive to heat damage than many other foods. A recirculation evaporator is commonly used to evaporate to about 20% solids followed by a mechanically agitated evaporator to produce tomato paste at 40% or even 50% solids.
- Apple juice is concentrated in Australia mainly for use in the soft drinks industry which requires a bland product light in colour. Any evaporator using a vapour-induced film system should give a satisfactory product.
- Citrus juices are more sensitive to heat damage than apple juice. While satisfactory concentrates are obtained from vapour-induced film evaporators, significantly better quality is possible with evaporators giving very short residence times.

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Maturation Studies

using a Single-pea Maturometer*

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STUDIES of pea crops with the 143-pin commercial maturometer (Lynch and Mitchell 1953) have yielded information on the rate of maturation of commercial wrinkle-seeded pea crops under varying conditions, and they have made it possible to define optimal harvest time and to develop a system for the prediction of crop maturity.

To follow the progress of maturation of a crop of peas in detail, enough peas must be harvested on each successive day to enable maturometer readings to be made on the ungraded material as well as on each individual size grade in the crop. The total area sampled and the number of pods harvested is therefore relatively large, and because delays must be kept to a minimum it is necessary to use mechanical procedures for removing the peas from the pods. These factors tend to introduce effects that are difficult to assess; one effect (tenderization due to vining) has been discussed elsewhere (Casimir *et al.* 1967).

The 143-pin commercial maturometer measures only the average maturity of ungraded or size-graded samples and provides no information on maturity distribution within size grades. For the assessment of maturity within size grades in small-scale trials, as in the early stages of pea breeding programmes, or in studies of the influence of environmental factors on maturation rates, a procedure based on the puncturing of single peas offers certain advantages. One of these is that because fewer pods are collected from each area sampled, the peas may be shelled by hand, thereby obviating the damage caused by the vining machine.

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Experimental Methods

In a crop of Perfected Freezer 60 peas grown by the authors at the Darrow Farm of the New York State Agricultural Experiment Station, Geneva, N.Y., in 1963, randomly chosen plots of 2 sq yd were harvested from each of 2 blocks at 4 harvest times. At each harvest the vines from these plots were bulked and thoroughly mixed, and the peas were removed from the pods by hand shelling. The total weight and the number of peas in each size grade were determined, and these data were used to calculate the average weight of peas in each size grade, and the size grade distribution within the sample by weight and by number. The single-pea maturometer reading (S.P.M.R.) on each of 44 peas from each size grade was then determined, using an Instron Universal Testing Machine Model TTCM as described by Casimir *et al.* (1967).

Results and Discussion

At each harvest the S.P.M.R. of each pea in a sample from each size grade was determined, and recorded in terms of the number of peas in texture categories 300–400, 400–500, 500–600 up to a force registration of 2600 g on the single pea maturometer. These data were combined with the numerical distribution of the size grades within the crop to assess the texture or maturity contribution of the size grades to the overall maturity of the crop. The results are expressed in Figure 1 in the form of numerical texture distributions, each diagram representing one of the four harvest times. In each diagram two maturity scales are shown—one based on S.P.M.R. and the other on alcohol-insoluble solids (A.I.S.). The latter was obtained by using the following regression (Casimir *et al.* 1967) for peas from the same crop:

$$\text{A.I.S. } \% = 0 \cdot 0129 \text{ S.P.M.R.} - 0 \cdot 674.$$

(The correlation coefficient r was $+0 \cdot 990$.)

Figure 1 presents a picture of the maturation of a single crop of green peas, and may be used to find:

the estimated average maturity of the whole crop (combining sizes 2 and larger);

the average maturity of peas of each size grade;

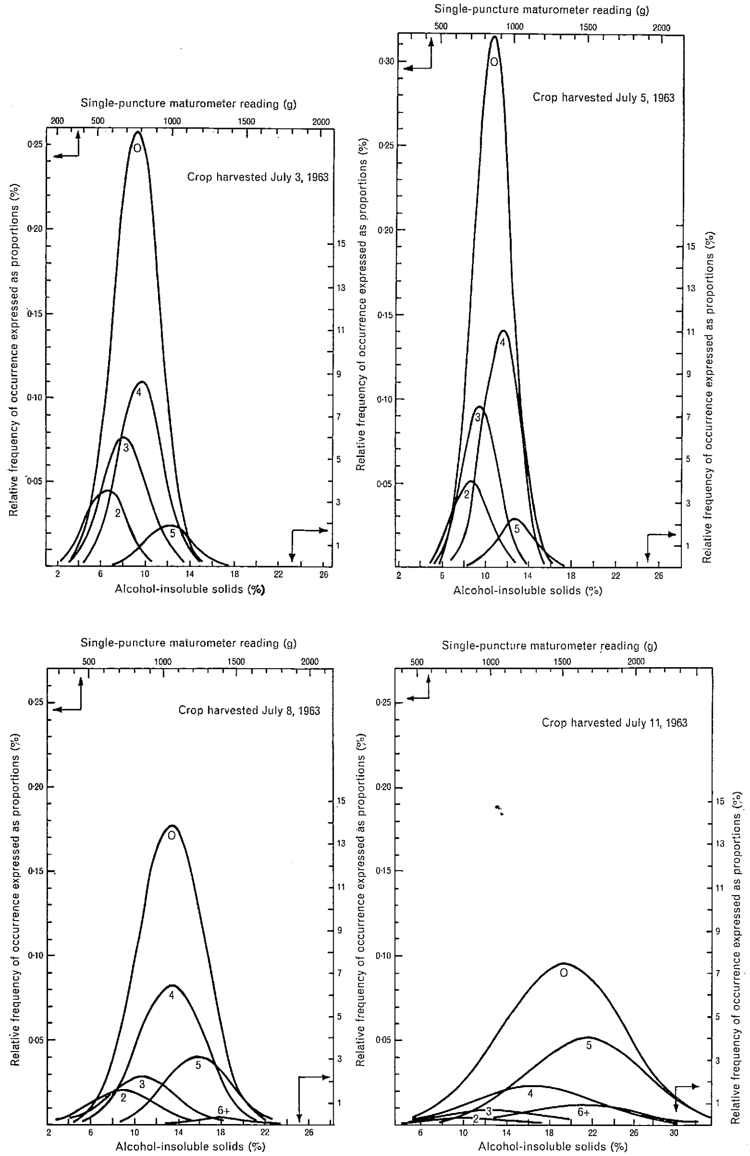

Fig. 1.—Distribution of maturity at four harvest times within a crop of Perfected Freezer 60 peas grown at the New York State Agricultural Experiment Station.

Table 1

Estimated Percentages (by Number) of Peas in the 11–16% A.I.S. Range

Date	Mean A.I.S. of Ungraded Peas (%)	Percentage of Peas within the 11–16% A.I.S. Range in Designated Size Grades						Percentage of Peas in the Ungraded Crop				
		Overall	Size 2	Size 3	Size 4	Size 5	Size 6+	Size 2	Size 3	Size 4	Size 5	Size 6+
July 3	9·2	19	0	12	24	66	0	17·5	30·0	42·4	9·6	0·5
July 5	10·2	41	5	27	64	81	0	16·0	30·1	44·5	8·9	0·5
July 8	12·9	58	27	51	60	48	15	11·0	16·2	46·8	23·8	2·2
July 11	18·7	21	26	40	30	14	14	2·8	8·5	23·7	53·2	11·8

the maturity spread within the crop and within each size grade;
the proportion of the whole crop, and of each size grade, that falls within specified A.I.S. limits.

Table 1 shows, by way of example, the percentage of peas having A.I.S. values in the range 11–16%, derived from the distributions at the four harvests shown in Figure 1. The 11–16% A.I.S. range was chosen because Lynch and Mitchell (1950) showed that it yielded canned peas of the best organoleptic quality.

The percentage of peas by number in the crop lying within this A.I.S. range is determined by erecting verticals from the 11 and 16% points on the abscissa to the O curve and expressing the enclosed area as a percentage of the total area under the distribution curve. The percentage of peas lying in this range can be similarly determined for each size grade.

The figures reproduced in this article are based on numbers of peas, but it would also be possible to graph the distribution as a percentage contribution by weight within the total crop or within the individual size grades.

Conclusion

The single-pea maturometer permits the detailed appraisal of the maturation characteristics of a pea crop in terms of the means and standard deviations of the whole crop and component size grades. The technique is most useful when only small numbers of peas are available. It should now be possible to evaluate the maturation characteristics of new varieties at an early stage, and to make maturation studies on peas grown in environmental chambers.

This technique also offers interesting possibilities for continuous on-line quality control in commercial pea processing plants. A continuous sample of the cleaned peas entering the plant from the size grader or other appropriate point on the line could be automatically fed to a single-pea maturometer. The data, displayed on a statistical digital voltmeter, would give the texture (or quality) distribution profile of the sample for commercial quality control procedures. Details of maturity distribution as well as average maturity would make possible the allocation of a quality grade on a more precise basis or demonstrate the need to grade the peas according to specific gravity.

Acknowledgment

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NEWS FROM THE DIVISION OF FOOD PRESERVATION

Appointments

There were two additions to the research staff of the Meat Research Laboratory at Cannon Hill, Qld., in the first half of 1968. Dr. R. J. Park, a graduate of the University of Queensland, is studying the degradative changes in the non-protein constituents of meat during its storage in the frozen state. Dr. D. A. Ledward, who obtained his Ph.D. in the Department of Food and Leather Science at the University of Leeds, is investigating the colour of meat and meat products and changes in their pigments during processing and storage.

Dr. B. D. Patterson, a plant biochemist who was awarded his Ph.D. by the University of Leeds in 1965, has joined the Plant Physiology Unit at North Ryde to study the initial stages of the senescence of leaves and ripening of fruit.

Overseas Travel

Several members of the Division's scientific staff were overseas in the first half of 1968.

Dr. D. G. Graham, of the Division's Plant Physiology Unit, was granted a Fellowship of the Cabot Foundation, tenable at Harvard University for 10½ months, from July 1968. Dr. Graham is working with Professor R. P. Levine in the Biological Sciences Laboratory at Harvard on photosynthesis and chloroplast biogenesis. Dr. Graham left Australia in April to visit laboratories in Great Britain and Europe before proceeding to the United States.

Dr. K. E. Murray, who is leader of flavour investigations in the Division, spent about 12 weeks overseas from mid April 1968 visiting major institutions and prominent individual workers engaged in food flavour research. He visited the United States, Great Britain, and the continent of Europe, and attended the 7th International Symposium on Gas Chromatography in Copenhagen.

Dr. E. F. L. J. Anet accepted an invitation from Refined Syrups and Sugars Inc., New York, to participate in a Gordon Research Conference on Carbohydrates held in New York from June 10 to 14, 1968.

Mr. J. F. Kefford, an Assistant Chief of the Division and Head of the Food Technology Section, visited Indonesia from May 27 to June 1, 1968. Mr. Kefford represented Australia at a conference in Djarkata organized by the National Academy of Sciences of U.S.A. and the Indonesian Institute of Sciences. The purpose of the conference was to assist in formulating a national food policy, with specific reference to Indonesia's five-year plan, which is scheduled to begin in January 1969.

Guest Workers

Mr. Wasim A. Farooqi, an officer of the Pakistan Atomic Energy Commission in Karachi, is spending 1968 and 1969 in the Fruit Storage Section of the Division of Food Preservation on a Colombo Plan Fellowship. Mr. Farooqi is engaged on a research project in post-harvest physiology. He is also attending lectures in several subjects at Macquarie University.

Mr. Bih-keng Wu, a United Nations Fellow from the Food Processing Institute, Taiwan, has been a member of the Food Technology Section of the Division since March 1968. He is carrying out an investigation on the flame sterilization of foods, and pursuing studies at the University of New South Wales.

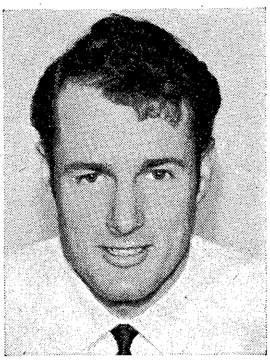
Fifth International Congress on Canned Foods

The International Permanent Committee on Canned Foods (C.I.P.C.) has issued a General Report on the above Congress, which was held in Vienna, Austria, in October 1967. The report comprises a large number of papers on the technical and economic aspects of canned foods, a summary of discussions, and a list of resolutions passed by the Congress.

The report may be obtained by sending a bank draft for 60 French francs to the International Permanent Committee on Canned Foods, 3, rue de Logelbach, Paris 17ème, France.

Food Technology Liaison

With the object of accelerating the application of technological developments in the food industry, the CSIRO Division of Food Preservation has appointed Mr. Keith Richardson as a Food Technology Liaison Officer to strengthen the links between the Division and the food industry throughout Australia.



Mr. Keith Richardson

Mr. Richardson is a graduate in microbiology and biochemistry from the University of Queensland, and has a background of experience which fits him admirably for this assignment of liaison with the food industry. For four years he was employed as bacteriologist in the Queensland Government's Food Preservation Research Laboratory, Hamilton, Brisbane, where he worked on vinegar manufacture from fruit wastes, and on microbiological problems associated with the preservation of fruits and vegetables. Subsequently he joined the staff of the Research Division of Petersville Ltd., where he was concerned with microbiological problems of the frozen food industry.

Although the Division of Food Preservation has always sought to maintain close contacts with the food industry, it is concerned about the slow application of many developments that arise in its own laboratories and overseas. Positive promotion of new processes and products of potential value to the Australian food industry will be part of Mr. Richardson's task. In addition he will be ready to assist food manufacturers with inquiries and trouble-shooting problems that they might refer to the Division. Mr. Richardson's appointment is not intended, however, to interfere in any way with direct contact between food manufacturers and individual officers of the Division.

New Abstracting Journal

As the food technologists of the world cannot meet frequently to exchange ideas, knowledge must be communicated by printed sources. The tracing of recent accounts of particular processes and foods in journals, however, has not been easy. From January 1969 the task will be simplified by the appearance of a new journal, *Food Science and Technology Abstracts*.

Such a journal has been needed ever since the British *Food Science Abstracts* ceased publication in 1957, but no country could finance the venture alone. After 10 years of inquiry and negotiation a joint body has been set up by the Commonwealth Agricultural Bureaux in England, Institute of Food Technologists of U.S.A., and Institut für Dokumentswesen of the Federal German Republic to produce it.

About 1000 journals carrying articles on all branches of the food industries will be searched regularly at the Commonwealth Bureau of Dairy Science and Technology, and about 1000 abstracts of articles therein and of world patents will be included in each monthly issue of the journal, together with reviews of new books.

The Institute in the Federal German Republic will print the journal and prepare the monthly and annual author and subject indexes by computer. As well as printing the information it will store references on magnetic tape, which it hopes to use later for listing articles on particular subjects to order.

Food Science and Technology Abstracts will be invaluable in libraries and relieve them of the work of indexing. The coverage will be so wide and the information contained so great that for small companies in the food industries, it could be a substitute for a librarian and a well-stocked library.

Orders may be sent now to the Central Sales Branch, Commonwealth Agricultural Bureaux, Farnham Royal, Bucks., England. The annual subscription is £75 stg.

Recent Publications of the Division

Copies of most of these papers are available from the Librarian, Division of Food Preservation, Box 43, P.O., Ryde, N.S.W. 2112. (Telephone 88 0233.)

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MELLOR, J. D. (1967).—Recent developments in freeze drying in Australia and overseas. *Fd Technol. Aust.* **19**, 652.

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