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Some Basic Questions of Fruit Storage

By F. E. Huelin

Division of Food Preservation, CSIRO, Ryde, N.S.W.

In this article Dr. Huelin sets down a number of concepts and questions that have been formulated after four decades spent studying fresh fruit storage in general and one area of this field in particular. Although these observations are primarily concerned with fleshy fruits, some of the concepts apply to other plant parts.

We are indebted to Kidd and West for emphasizing that stored fruits and vegetables are living tissues. As a result of this emphasis the concept of senescence was applied to the deterioration of such plant organs in storage, and their functional disorders were regarded as death of the tissue for which external or internal causes must be sought. The science which has come from this approach is now known as post-harvest physiology. However, the science of fruit and vegetable storage includes not only post-harvest physiology, which is strictly concerned only with plant function, but also the study of these tissues as human food. Changes in both plant function and acceptability of the tissue as food enter into the discussion of storage problems, and it is necessary in each instance to distinguish clearly what we are considering. Usually both aspects are involved, but one may predominate in a particular phenomenon.

Senescence and Ripening

In physiological terms, senescence is the stage when growth has ceased and there is a progressive loss of organization and of resistance to fungal attack. Loss of organization in ripening Williams pears was described by Bain and Mercer (1964). In normal senescence, a variable dormant period with little obvious change is succeeded by ripening changes which result in the fruit becoming first fully ripe and then over-ripe. Physiologically the fruit is passing through a period of continuous decline, but as an article of food it is fully ripe at the point of maximum acceptability to the consumer. In the progressive disorganization of normal senescence, no point has been observed where the fruit can be said to pass from the living to the dead state. The fruit finally succumbs to fungal attack due to loss of resistance.

'Normal senescence' is here taken to mean the senescence that occurs under conditions which do not result in abnormal ripening, chilling injury, and other disorders. It is, of course, the senescence that gives a product acceptable to the consumer, but the distinction may be claimed to have physiological significance, as normal senescence is free from the disorders that show the clearest symptoms of dead tissue. In a normal senescence, the fruit is often most susceptible to chilling and other forms of injury in the period of most rapid ripening changes.

The initiation of ripening is usually accompanied by a marked rise in respiration, which Kidd and West (1924*a*) called the climacteric. Respiration has been most commonly used for following senescence, and much effort has been devoted to finding the respiratory system responsible for the climacteric. Hulme, Jones, and Wooltorton (1963) found increased malic enzyme and pyruvic carboxylase, and Hartmann (1963) found increased aldolase activity associated with the climacteric in apples. Hartmann (1962, 1963) found increases in pyruvic carboxylase and aldolase in pears, and Tager (1956) found similar increases in bananas. However, Barker and Solomos (1962) obtained evidence in support of their view that the climacteric in bananas is due to the increased concentration of fructose diphosphate. It is suggested that the controlling or limiting reaction in the respiratory chain may vary from fruit to fruit, and that it is of little significance in senescence and ripening. The climacteric of respiration appears to be only one aspect of a general rise in metabolic activity, and it is doubtful whether respiration can be regarded generally as the controlling process. It can be assumed that respiration supplies the energy for the synthesis of enzymes involved in other reactions, but there is no evidence that the level of respiration is such as to limit the supply of such energy during normal senescence. It is still possible that the inhibition of some ripening changes at low temperatures or in low concentrations of oxygen is due to limitation of energy supply, but the connection with respiration is more likely to be established by investigating first the ripening process and then the conditions necessary for synthesis or activation of the appropriate enzymes.

Of all the metabolic processes which are involved in senescence, it is surprising that so little attention has been given to those recognized as ripening processes, i.e. changes of colour, texture, and flavour. Change of colour, due to loss of chlorophyll and sometimes synthesis of carotenoids, generally but not always accompanies normal ripening. The change of texture, in which the fruit becomes softer and more juicy, is due to degradation of the polysaccharides of the primary and secondary cell walls and middle lamella. Work with these polysaccharides is difficult as the major change, the conversion of protopectin to soluble pectin, is still not understood. McCready and McComb (1954) found that it involved a decrease of molecular size in peaches, pears, and avocados, but Doesburg (1957) found no change of molecular weight in apples. Changes in the combinations with hemicellulose and calcium have also been suggested. The enzymes polygalacturonase and trans-eliminase may be involved in the degradation of pectin, and non-enzymic splitting is also possible (Griffin and Kertesz 1946; Albersheim, Neukom, and Deuel 1960).

The changes of flavour are complex, as they involve loss of acidity, loss of astringency associated with tannins or phenolic substances, and changes in the volatile constituents of the aroma. The composition of the aroma varies from fruit to fruit with no sign of a common pattern.

Ethylene and Dormancy

The dormant period before the initiation of ripening is of considerable physiological and practical importance. Extension of the dormant period offers obvious possibilities of increasing the storage life. On the other hand, there is sometimes a problem in breaking dormancy and initiating ripening when required.

The importance of ethylene in breaking dormancy is now recognized by most workers, but there appear to be other factors which require identification. It is common experience that applied ethylene causes immediate ripening of all except very early picked fruit. In the absence of applied ethylene, the fruit's own ethylene appears to play a part, although this is in comparatively low concentration before ripening starts. As dormancy is sometimes broken at levels of ethylene not appreciably higher than those present earlier in the dormant period, it has been postulated (Mapson 1970) that the disappearance of a restraining factor is also involved. The identification of this factor, which is assumed to desensitize the tissue to low concentrations of ethylene, would be of great value in controlling dormancy. In the absence of applied ethylene, Anjou pears seem to need a period in cold storage before ripening can be initiated at higher temperatures (Porritt 1964). Do ethylene and low temperatures break dormancy through a similar mechanism? Ethylene appears to be less effective at low temperatures (Fidler 1954).

In view of the major role of ethylene in senescence and ripening, the problems of its biogenesis and mechanism of action need considerable attention. On present evidence the most likely path of biogenesis is from methionine through 4-methylmercapto-2-oxobutyric acid and 3-methylmercaptopropionaldehyde (Mapson, March, and Wardale 1969; Ku, Yang, and Pratt 1969; Takeo and Lieberman 1969). The evidence for this or any other path would be strengthened if the changes in precursors and enzyme systems could be related to the course of ethylene production during senescence. It would also be worth determining whether the ethylene production comes predominantly from one tissue within the fruit, as metabolic processes peculiar to this tissue could provide clues to the biogenesis.

The major problem of the mechanism of action of ethylene concerns the initial reaction which leads to the ultimate biological effects. Burg and Burg (1965), after comparing the biological activity of ethylene and other unsaturated compounds, suggested that ethylene binds to a metallic receptor site in the tissues. Work with tissues which do not ripen and in which the effect of ethylene is reversible might help to identify the initial reaction. Potatoes appear to fit this requirement (Huelin and Barker 1939; Reid and Pratt 1970), and the fate of labelled ethylene in this tissue would be worth investigation.

Maturity

Discussion of the problems of maturity is at present extremely confused. Solution of the problems is difficult enough if they are clearly stated. The lack of clarity is due to the use of different meanings for 'maturity' and 'maturation'.

When people want an answer to a problem of maturity, they invariably have a particular purpose in mind. They may want an objective measurement to determine whether the fruit is being picked too early (immature), just right (mature), or too late (over-mature) for maximum eating quality. For processing the optimum stage would generally be earlier than for eating raw. Maturity for storage is concerned with potential eating quality and freedom from disorders, and may differ according to the length of storage. This meaning of maturity is quite definite if the particular purpose is specified. It is the meaning I prefer, as it enables questions to be posed for which answers are required. If the word 'maturity' with this meaning were abandoned, another word would have to be found.

I have avoided the use of 'maturity' and 'maturation' for stages in the life of the fruit. The introduction of 'maturation' as a stage between growth and senescence is confusing, particularly as the stage is not clearly defined. 'Maturation' is sometimes used to include ripening, 'senescence' being used for subsequent deterioration. This division is related purely to use as human food, and has no relation to plant function. Alternatively, 'maturation' has been confined to the dormant period before ripening starts. In this paper I am using 'senescence' to cover the whole life from picking or the cessation of growth on the plant. It seems best to regard this as a stage of continuous decline. It can be divided into the pre-ripening (dormant), ripening, and post-ripening periods.

Returning to the problems of maturity for particular purposes, maturity for immediate consumption is ultimately judged by the senses. The need for objective measurements arises from the requirements of government supervision or commerce. Colour and texture are most readily determined by physical measurements, which are likely to be as adequate as any chemical determination. Flavour is the most difficult for objective measurement. Titratable acidity or the soluble solids : acid ratio is used for oranges, but this is only one aspect of flavour. In regard to astringency, the methods for tannins are based on their reducing properties and are not very specific. Investigation of the volatile constituents might lead to the identification of those most responsible for the aroma and to convenient methods for their determination. This is still a very open question.

The problems of maturity for storage are more complex and difficult, because they require the measurement of a capacity for developing and retaining desirable qualities in the future. In some cases later picking gives a product with maximum quality for immediate consumption but with a shorter storage life than earlier-picked fruit. The selection of the most suitable maturity involves some compromise. Fruits differ in the stage at which they can be picked and develop full eating quality in subsequent storage. Grapes do not ripen appreciably off the vine, and the requirements of maturity for immediate consumption or for storage are practically the same. Peaches need to show some signs of ripening at picking if they are to become fully ripe after storage. At the other extreme pears and bananas can be picked hard and green with a capacity for subsequent normal ripening. Even for such unripe fruits, which differ little in colour and texture, there are still questions of maturity, because the earlier-picked fruit may develop poorer quality on ripening and have a longer or a shorter storage life than the later-picked fruit.

In regard to fruits picked before they are fully ripe, empirical correlations of measurements at picking with subsequent quality in storage have been of limited value. There is need for a fundamental investigation of what determines the capacity for subsequent changes in colour, texture, and flavour. The investigation would include studies of the appropriate reactions and enzyme systems and then lead back to the synthesis or activation of these enzymes. This approach should have some hope of identifying the differences at picking which lead to differences in quality on subsequent storage.

The subject of maturity poses very difficult questions. I have tried to make them as clear as possible.

Effect of Temperature

Low temperature retards ripening and increases the storage life in the absence of chilling injury. Investigations on the cause and control of the different forms of chilling injury are necessary to obtain maximum benefit from cold storage.

Some disorders show a marked increase from zero to high incidence on lowering the temperature through a narrow critical range. The analogy to a change of physical state is sufficient to suggest that this may be the cause. As chilling injury by definition excludes freezing of water in the tissue, the crystallization of lipids could be involved. It is likely that the lipids of subcellular membranes and organelles are normally in a liquid state and that crystallization could cause serious damage. Microscopic detection of crystallized lipids in the tissue, even with the aid of polarized light, is not very likely, in view of their intimate association with proteins at the molecular level. A differential thermal analysis of the extracted lipid could give results of interest. Lyons, Wheaton, and Pratt (1964) found the mitochondria of chilling-resistant plants to have a higher content of unsaturated fatty acids than mitochondria from sensitive plants. The more unsaturated lipids tend to remain liquid at lower temperatures. Lyons and Raison (1970) obtained evidence of a phase change in the mitochondria of chilling-sensitive tissues on lowering the temperature through the critical range.

The alternative explanation of a disturbance of the metabolic balance was suggested by Kidd and West (1924*b*). According to this theory, the rates of different metabolic processes decrease with falling temperature in different proportions until the balance is altered sufficiently to cause injury through accumulation of toxic intermediates or through other mechanisms. Hulme, Smith, and Wooltorton (1964) obtained evidence for the accumulation of oxaloacetic and other acids of the Krebs cycle at low temperatures and their association with breakdown in apples. Wills, Scott, and McGlasson (1970) found a relation between acetic acid and breakdown.

The phenomena of latent injury more readily fit the latter theory of a disturbance of the metabolic balance. Sometimes the fruit is free from disorders after a certain period at low temperature but develops a chilling disorder within a few days of removal to a higher temperature, which is not injurious for continuous storage. Although the fruit is still sound at removal, it has reached a point where the progress to chilling injury cannot be reversed or even stopped by removal from the chilling temperature. These phenomena cannot be explained in terms of a disturbance which is readily reversible. But if the disturbance extends to the differential synthesis or activation of enzymes, the altered metabolism which leads to injury may only accelerate on raising the temperature.

The disturbance of the ripening processes of pears, peaches, and plums at low temperature is well worth investigation. These fruits can be kept in cold storage only for limited periods if they are to ripen normally on removal to higher temperatures. Over-stored fruits ripen abnormally and develop disorders. The abnormal change of texture, in which the fruit softens but becomes mealy or gelatinous instead of juicy, merits close study as a typical example of a metabolic process disorganized by low temperature. The failure to exude juice under pressure may be due to the preferential dissolution of the middle lamella allowing separation without disruption of cells. The loss of ripening capacity during cold storage also needs investigation. Failure of the systems responsible for the synthesis or activation of certain enzymes may be involved. The abnormal senescence of pears at low temperature, which leads ultimately to death of the whole tissue (as indicated by general discoloration and absence of respiration), is an extreme case worth fundamental study.

Effect of Carbon Dioxide

The mechanism of the retarding effect of carbon dioxide on ripening is still not understood. Burg and Burg (1965) suggested that carbon dioxide competes with ethylene for a metallic receptor site in the tissues. Carbon dioxide may also affect some reversible reactions as substrate or product.

Carbon dioxide can extend the storage life only if injurious concentrations are avoided. The mechanism of injury has been given some attention. Hulme (1956) found an association between carbon dioxide and accumulation of succinic acid in apples, and Williams and Patterson (1964) found a similar association in pears. An effect of carbon dioxide on the pH of certain regions of the cell is also possible.

General Comments

I have indicated some areas in the science of fruit and vegetable storage where further research is needed. One should still watch for unrecognized factors, perception of which could lead to major advances. The present considerable knowledge of the major role of ethylene in plant physiology came originally from chance observations. Some unexplained observations, which have been given no further attention, belong to the so-called 'shell effect'. In Melbourne in 1940 I observed that Williams pears scalded much earlier in cases than in respiration shells. For respiration each pear was enclosed in a spherical shell through which CO_2-free air was drawn. When I met the workers at Homebush next year, I found that they had observed a similar effect with apples. Enclosing the apples in shells retarded the fall in internal oxygen and the increase in resistance to gas exchange during storage. The shell effect may be due to variations in pressure associated with the control of air flow or to comparatively high rates of flow over areas of the fruit next to the shell.

I have made no direct comments on cultural or pre-storage factors, as I have had no experience in this field. I can only point out that understanding of storage problems will not be complete until we know at every stage what conditions in the fruit determine the subsequent storage behaviour and how these conditions are the result of the fruit's previous history. Samples which will respond differently to the same environment should show some differences now, if they could only be detected.

Senescence and ripening are reviewed by Biale (1960), Biale and Young (1962), Hansen (1966), and Patterson *et al.* (1970). Chilling injury is reviewed by Huelin (1962) and Fidler (1968).

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Transport and Handling of Frozen Foods

By J. H. Last
Division of Food Preservation, CSIRO, Ryde, N.S.W.

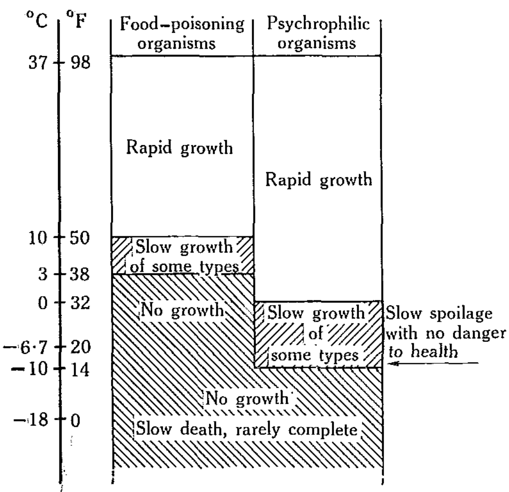
This article is based on a talk given at a Frozen Food Seminar of the Southern Section of the Australian Institute of Food Science and Technology held in Melbourne on September 24, 1969.

Preservation of food by quick freezing relies upon the reduction with temperature of the rate of microbiological and chemical changes that cause food spoilage and deterioration, thus permitting storage of food for a commercially useful period. With some foods it is necessary to use additional treatments, e.g. blanching or addition of antioxidants.

The effect of temperature on the growth of food-poisoning and psychrophilic bacteria is shown in the diagram. Bacteria responsible for food poisoning have not been known to grow at temperatures lower than 38°F (Schmidt, Lechowich, and Folinazzo 1961) but they may survive chilling and freezing. However, since these bacteria must grow for them to cause food poisoning, foods that remain in a frozen condition almost certainly will not present a food-poisoning hazard. Frozen foods can only present a food-poisoning risk if they have been mishandled by the processor, the distributor, or the consumer.

Although bacteria responsible for poisoning will not grow at temperatures lower than 38°F, psychrophilic organisms, which may cause food spoilage, will grow at temperatures down to 14°F (Elliott and Michener 1960).

However, there are adverse biochemical reactions that may occur at temperatures below 14°F. Many of these reactions involve enzyme-catalysed oxidations and they may cause serious deterioration in the quality of frozen foods. Enzymes are inactivated by blanching or controlled by the addition of an antioxidant such as ascorbic acid or sulphur dioxide.



Effect of temperature on microbial growth.

Storage

Experience over many years has shown that most foods that have been correctly processed, packaged, and frozen will have a commercially acceptable storage life if the temperature does not exceed 0°F. Recent European practice, however, aims at a temperature of −20°F for the extended storage of frozen foods, especially for those that are more temperature-sensitive, e.g. fish. The expected storage life of frozen products at 0°F is shown in Table 1.

The effect of storage temperature, both constant and fluctuating, on the quality of quick-frozen foods has been widely studied, particularly by the Western Regional Laboratory of the United States Department of Agriculture (U.S.D.A.), and the findings have been summarized by Van Arsdel (1969). The experiments, which were concerned primarily with frozen fruits, vegetables, and poultry, were designed to simulate temperature conditions that might occur during storage and distribution. The results showed that:

- Most frozen foods must be kept at 0°F to ensure the required commercial storage life.

- For every increase of 5 degF above 0°F, the rate of deterioration may be doubled.

- The rate of quality loss due to fluctuating storage temperature is nearly the same as if the foods were maintained at the effective mean temperature.

- Losses of quality are additive and cannot be reversed. Therefore even though the occurrence of a single adverse time–temperature experience is not detectable, it cannot be assumed to be unimportant to the final quality of product.

- An adverse time–temperature experience has the same effect upon the quality of a given food regardless of the stage of storage or distribution at which it occurs.

Table 1*

Expected Storage Life (months) of Frozen Products at 0°F†

Fruits	
Peaches in sugar and ascorbic acid	12
Raspberries in sugar	18
Strawberries in sugar	12
Vegetables	
Beans, snap	8–10
Broccoli	12
Peas	8–12
Potatoes, french fried	6
Meat	
Beef	8–12
Lamb	6–10
Pork	4–6
Poultry	6–8
Fried chicken	3–4
Marine products	
Fatty fish	2–3
Lean fish	3–5
Flat fish	4–6
Prawns	6
Baked or precooked foods	
Bread, yeast	6–12
Pies	1–6
Sandwiches	2
Meals, complete dinners	2–3

* Adapted from data published in 'Recommendations for the processing and handling of frozen foods'. Int. Inst. Refrig. 1964.

† Because of large deviations in the quality of raw material and packaging the expected storage life may vary over still wider ranges than indicated in this table.

While fluctuating storage temperature does not necessarily cause a loss of culinary quality, it does increase the rate of desiccation of the product and formation of frost in the package. In a few products, such as gravies and sauces, fluctuating temperatures can cause adverse changes which may not occur if the product is stored at the effective mean temperature.

These U.S.D.A. findings show that it is possible to calculate the equivalent storage time at 0°F for any known combination of handling and storage temperatures (Van Arsdel and Guadagni 1959). However, such calculations require complete and accurate product temperature histories. Simple instruments that integrate these fluctuations are available. Based upon an electrochemical reaction that causes a progressive colour change along a paper strip, the instruments are calibrated to give full-colour migration with exposures equivalent to periods at 0°F ranging from one week to one year. Examination of such a time–temperature indicator packed with a frozen food at the time of processing shows immediately the acceptable storage life remaining at 0°F (Anon. 1961).

Foods are frozen either before or after packaging. Loose frozen foods can be packaged before storage or they can be stored in bulk bins holding from 1000 to 3000 pounds of product, or in silos holding perhaps five million pounds of product. Bulk storage, by permitting packaging all the year round instead of in the processing season only, permits more economic use of equipment and staff, and avoids the need to predict the likely demand for the various-sized packages over a full year.

The first processor to build a silo used a large room with cavity walls and he stored peas and corn. The external wall was insulated and air at −20 to −25°F was circulated between the walls to remove the heat entering through them. The silo was 21 ft high, 67 ft wide, and 100 ft long, and was divided into 25 compartments to hold the different grades of peas and corn. The silo was filled by pneumatically conveying the product through a pipe into the top of the appropriate bin. To remove the stored material a flexible hose was lowered into the product and a vacuum was applied. The entire conveyor system was constructed in such a way that outside air could not enter. A filtration system was used to remove entrained frost and dust from the circulating air (Cedargreen and Robe 1964).

This method of storage is claimed to use less than half the refrigeration required for normal methods of storage, and as there are no aisles the storage space is more fully used. There is no air circulation in the storage compartments, so desiccation is minimized, but for the system to be effective the product must be at the storage temperature when it enters the silo.

In all phases of the handling of frozen foods, whether in the processors' or distributors' cold stores, in the retailers' cabinets, or during transport to or from these places, the hazard of temperature fluctuations is always present.

The processor must ensure that the product temperature is reduced to the cold store temperature in the freezer before it is placed in the cold store, which should be run at 0°F or below. Failure to do this, which may result from overloading of the freezer, will result in a rise in temperature in the cold store. The foods already in the cold store may then be affected. If a product at an elevated temperature is tight-stowed or stored in bulk bins or silos it may take days or weeks to approach the cold store temperature, and during this time the product is deteriorating at a faster rate than it would have done if it had been put into store at the correct temperature.

Stacking

In cold stores and transport vehicles, cartons should be stacked in a manner that will not hinder air circulation and they should not be stacked in direct contact with the walls or floors. If packages are stored in direct contact with the walls or floors heat entering through them will directly heat the food without giving the refrigeration unit a chance to remove it. An air space of at least 6 in. should be left between the food packages and the cold store walls or pipes, with at least 4 in. between the stored food and the floor; the cartons should be stacked no closer to the ceiling than 12 in. The air circulation should be just sufficient to achieve uniform temperature distribution within the store. Excessive air circulation and fluctuating storage temperature increase product desiccation.

Transport

Once the foods have been correctly processed, packaged, and frozen they must be conveyed to the consumer with minimum loss of quality. Frozen foods suffer most mishandling during transfer between storage points. Loading and unloading of transport vehicles at cold stores is often conducted over open docks and may take two hours or longer to complete. During this time the product is exposed to ambient conditions and its temperature may rise about 10 degF. Even if the vehicle had the refrigeration capacity needed to remove this heat, the tight stowage that is required for load stability would not allow much cooling during transit. Unloading is a less severe hazard than loading as the product can be open-stacked in the cold room, which should have a high cooling capacity.

Precooling of Compartments

When transporting frozen foods it is essential to precool the container compartment. The cooling unit should be turned off while the vehicle doors are open to prevent rapid frosting of the evaporator. The use of concertina sleeves or soft rubber gaskets between the cold room door and the transport vehicle reduces heat uptake, and the use of pallets reduces the loading time. Cartons can be stacked on the pallets before loading starts and the pallets are quickly loaded into the vehicle on its arrival. This requires standardization of both the pallets and the cartons but the benefits in terms of product quality are considerable, apart from the economic returns which result from reducing loading times from 2–3 hr to 15–30 min.

Insulation of Compartments

In Australia, most road vehicles used for the transport of frozen foods have four to six inches of insulation, mainly foamed polyurethane, which is faced with polished aluminium sheet or with fibreglass. Insulation and other fabricated plastic containers may contain solvents and other volatile organic compounds, which if not effectively removed from new containers may taint the food.

The insulation used must have a low thermal conductivity and an extremely low water vapour permeability and must be light and strong. The outer protective covering and the inner lining must be waterproof and easy to clean. The inner lining must be waterproof because any water that lodges between the lining and insulation will expand upon freezing and crush the insulation. The thermal conductivity of the insulation is then increased and more refrigeration is needed to maintain the required temperature. This ice layer gradually builds up and eventually the insulation will be rendered useless.

Liquefied Gas Refrigeration

Refrigeration units on transport vehicles are designed only to remove heat that is conducted through the walls of the storage container, they are not designed to cool the load. Therefore, the cargo temperature must be at, or below, the required transport temperature when it is loaded.

Most transports for frozen food are mechanically refrigerated but the use of liquefied gases, such as carbon dioxide and nitrogen, as refrigerants is increasing. In other countries, especially in North America and Europe, three different refrigeration systems are used in long-distance transports:

- The temperature of the product is reduced to a level that permits several days' journey in an insulated but unrefrigerated vehicle.

- Liquefied gases are used in conjunction with mechanical refrigeration. Liquefied gas is sprayed over the load as soon as loading is completed, to remove quickly the heat taken up during loading. A mechanical unit provides the refrigeration for the remainder of the journey.

- The liquefied gas from a bulk storage tank located inside or underneath the vehicle is automatically injected through a spray header into the load when the temperature exceeds a set figure.

The last method is the most widely used. There are about 200 of these units in use in Australia and about 10,000 in the world, but not all of them are used for transporting frozen foods. The advantages of this method compared with mechanical refrigeration are:

- Lower investment and depreciation costs.

- Lower maintenance costs, since the system contains only one moving part—a solenoid valve—and non-earning, off-road costs are almost eliminated.

- It is more reliable.

- These units are silent and avoid the possibility of being switched off by the driver during compulsory rest periods, when he wishes to sleep.

- The units weigh less and allow more complete loading of the cargo space. The cargo can be loaded to the ceiling with minimum provision for gas circulation, since liquid nitrogen, on vaporization, expands 600-fold and forces its way around the load.

- The rapid cool-down and more uniform temperature control enable the carrier to comply with the temperature requirements of the frozen food handling codes that have been introduced in a number of countries.

The key factor in the economics of this system is the cost of the liquefied gas. For minimum consumption good insulation is essential, and the product when loaded must be at or below the temperature at which it is to be carried. The marketers of this system claim that with the thermally efficient vehicles that are now in use, the cost is directly competitive with mechanical refrigeration for long-distance transport and also for retail delivery, provided there are no more than 30 door-openings per day. An increasing number of vehicles are being equipped with liquid nitrogen refrigeration both overseas and in Australia, so it is obviously a practical and economical system which could possibly supplant existing mechanical systems. It is also possible that as the number of vehicles equipped with liquid nitrogen increases, some reduction in operating costs will occur.

Closed-cycle Cryogenic Refrigeration

A closed-cycle cryogenic cooler that is one-sixth the size and one-tenth the weight of existing equipment has recently been announced (Anon. 1969*a*). The manufacturers claim that 'the new system promises significant cuts in operation costs since it provides twice the refrigerating capacity with substantially less than half the input power of competitive systems. Other savings are claimed through the decreased loss of the refrigerant by the self-cycling process, its miniaturized size and weight and other significant features.'

Should such a revolutionary break-through in transport refrigeration be substantiated, it could have a marked impact on the industry.

I.S.O. Containers

Many frozen foods are now being transported overseas in I.S.O. containers. The use of containers has brought about a substantial reduction in the handling of the goods and a consequent reduction in the likelihood of the hazard of temperature fluctuation (Middlehurst, Parker, and Coffey 1969).

The container sizes have been standardized at either 20 ft × 8 ft × 8 ft or 40 ft × 8 ft × 8 ft; the 20-ft length is the common size. On one wall there are two 10-in. diameter openings, one for admitting cold air from the ship's refrigeration system, the terminal stack system, or the slip-on units and the other for returning the air to the refrigeration system. The cold air flows from the lower openings, between the floor slats, up the back and sides of the container, and then over the top to the exit duct. The uniformity of air distribution is improved by the use of spreaders.

Delivery to the Retailer

Probably the greatest risk of temperature fluctuations in frozen food occurs during delivery to the retailer, usually in small vans that are refrigerated with dry ice, eutectic plates, mechanical units, or liquid nitrogen. In some instances only the insulation of the vehicle is relied on to control the rise in temperature of the product. Retail delivery is frequently carried out by a driver-salesman who collects the orders and makes them up in the back of the van. This necessitates lengthy door-openings and may result in large increases in product temperature. In Sydney during a normal delivery run at maximum ambient temperature of 85°F, with a well-insulated vehicle refrigerated with eutectic plates, product temperature has been reported to increase from −3°F on departure from the warehouse to 25°F for unsold goods returned 8 hr later (Shipton 1963). Such increases in temperature are particularly serious because retailers' display cabinets are not designed to cool products.

It is better to deliver pre-packaged orders; this reduces the time the driver is in the cargo section of the van and also the time to complete the run.

Liquid nitrogen, having a high heat extraction capacity, is an ideal refrigerant for use in retail delivery trucks, but to be economic, delivery arrangements must minimize heat loadings.

Liquid nitrogen will assure delivery at 0°F even with high heat gains, whereas mechanical units cannot provide this assurance.

Retail Display Cabinets

Retailers of frozen food should take the following precautions with display cabinets:

- Cabinets should not be exposed to strong draughts, direct sunlight, or heating from any other equipment.

- The temperature should be checked regularly and the cabinet defrosted when necessary.

- Frozen foods should be put into the cabinet or storage room immediately they are received from the distributor.

- Packages should not be stacked above the load line.

- Stock should be rotated so they are sold on a first-in first-out basis.

- Cabinets should always be kept clean and orderly and damaged packages removed.

- Unfrozen products should never be put in the cabinet for freezing or storage as this could cause an increase in the temperature of the cabinet and harm to other stored goods.

Frozen Food Regulations

The mishandling of frozen foods has resulted in the formulation of handling codes in some countries. These codes are similar in their temperature specifications and generally provide for a product temperature not greater than 0°F. Some codes tolerate higher temperatures at various points of the distribution chain.

The proposed N.S.W. Frozen Food Regulations specify that the temperature of frozen foods must not rise above 5°F at any stage after processing except during retail delivery and storage, where a maximum of 10°F is permitted. At some future date it is intended that a maximum permissible temperature of 0°F will apply (Anon. 1969*b*).

Conclusion

Although the production of frozen foods has expanded rapidly, further improvement in transport and handling is possible. Expansion of production cannot be guaranteed unless every effort is made to eliminate temperature abuse and associated product deterioration.

What must be emphasized concerning the handling of frozen foods is that, if quality is to be retained, they must be stored at 0°F or below, and that even though a product is exposed to adverse temperatures for a short time it loses some quality which cannot be regained.

Therefore, to ensure that the quality of correctly processed frozen foods is maintained for the benefit of the consumer, the product temperature must not exceed 0°F at any stage during storage and handling. The facilities to achieve this are available and undoubtedly the further development of the industry will depend on the extent to which these facilities are employed.

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News from the Division

New Appointments

Mr. A. Graham joined the Meat Research Laboratory at Cannon Hill on October 5, as an Experimental Officer to work in the Industry Section on engineering aspects of operations in the meat industry. Mr. Graham graduated in mechanical engineering in Scotland and has been an engineer with the Queensland Works Department since arriving in Australia early in 1969.

On October 12 Dr. D. G. Laing was appointed as Research Scientist to the Flavour Chemistry Section at Ryde, where he will be working on sensory physiology. Dr. Laing graduated with first-class honours at the University of New South Wales in 1965 and obtained his Ph.D. degree from the same University in 1968. He has held a post-doctoral fellowship in the Department of Organic Chemistry at Cambridge University for the past two years. Dr. Laing will be spending several months in the School of Biological Sciences at Macquarie University, collaborating with a research group having interests related to the work of the Division's Flavour Chemistry Section.

Mr. L. S. Herbert, Principal Research Scientist, transferred from the CSIRO Division of Chemical Engineering to the Meat Research Laboratory at Cannon Hill, as from November 2, to lead the Physics–Engineering Section, with responsibility for research in heat and mass transfer, process development, and supervision of engineering work in the Industry Section. Mr. Herbert's interest for the past two and a half years has been the development of a batch rendering process for meat and he will continue to work in this field in his new position.

The Division has also made two appointments in microbial physiology to the research staff of the Meat Research Laboratory, Cannon Hill. Dr. A. F. Egan and Mr. R. R. B. Russell, who commenced work in November, will study the mechanism of growth and cell division in microorganisms, with special regard to environmental factors.

Dr. Egan is a graduate of the University of Sydney and obtained a Ph.D. degree at the University of Melbourne in 1967. Before joining the Division he was a Research Fellow in Biochemistry at Harvard University.

Mr. Russell came to Australia after graduating in Natural Sciences at Dublin University. He recently submitted his thesis for the degree of Ph.D. to the University of Melbourne.

Visiting Workers

Dr. Myron J. Powers, Associate Professor of Horticulture (Fruit and Vegetable Processing), Washington State University, is spending one year's sabbatical leave in the Food Technology Section from September 1.

Professor Irving L. Eaks of the School of Biological and Agricultural Sciences, University of California, Riverside, commenced a visit of nine months to the Plant Physiology Unit at Ryde, early in September.

Staff

Dr. J. R. Vickery, Senior Research Fellow and former Chief of the Division, has been elected a Foundation Fellow of the American Institute of Food Technologists.

Dr. N. L. Wade, Fruit Officer (Research), N.S.W. Department of Agriculture, who is located at Ryde, received the Ph.D. degree from the University of Sydney.

Mr. J. F. Kefford, Assistant Chief, has been elected Member of Executive Committee and Chairman of Education Committee, International Union of Food Science and Technology.

Mr. R. Atkins, Divisional Engineer, has been elected Vice-Chairman of the Agricultural Engineering Branch, Sydney Division, the Institution of Engineers, Australia.

Visits and Meetings

The CSIRO Advisory Council visited the Division on the afternoon of November 11. Mr. Tracey, Chief of Division, gave an address on the work of the Division and Mr. J. Middlehurst, leader of the Physics Section, reviewed the freeze drying project. Members of the Council then inspected the laboratories and were shown the work of the Food Technology, Flavour Chemistry, Microbiology, and Physics Sections.

Dr. E. G. Bollard, leader of the Plant Physiology group, Plant Diseases Division, and Mr. R. W. Foster, Industrial Development Division, both of DSIR, New Zealand, had discussions with members of the Fruit Storage Section and the Plant Physiology Unit.

Mr. M. V. Tracey, Chief of Division, attended the 18th International Dairy Congress in Sydney in October. The Division welcomed a number of distinguished visitors from France, U.S.A., and U.S.S.R., who were delegates at the Congress.

Mr. P. Davis, Senior Research Officer with the Fisheries Division of the Commonwealth Department of Primary Industry, was attached to the Division during October in connection with the proposed establishment of a Technical Advisory Service. He also visited the CSIRO Tasmanian Regional Laboratory, Hobart, where he had discussions with members of the Division engaged on fish investigations.

Sgt. Reck of the Army Research Station, Scottsdale, received training in the Division's Taste Test Unit during October.

Macquarie University and the Division arranged a joint Seminar on September 30 on the topic of 'Chemistry and Physiology of Flavour and Odour'. The main speakers were Dr. K. D. Cairncross and Dr. Murray King of the University and Dr. K. E. Murray and Mr. J. Shipton of the Division.

Dr. A. R. Johnson, leader of the Animal Products Section, returned to Australia on October 15 having completed a 12 months' attachment to the Unilever Research Laboratory at Sharnbrook, Bedfordshire, England.

Dr. Johnson and Mr. Shenstone attended the Australian Poultry Production Review Conference, held in Adelaide in November.

Drs. Smillie, Raison, Bishop, and Andersen, and Miss Chapman of the Plant Physiology Unit participated in a conference on photosynthesis at the Australian National University from November 22 to 27.

Citrus Wastage Research Laboratory

Mr. J. A. Seberry, Officer-in-Charge of the Gosford laboratory until October 19, has been promoted to Assistant Principal Fruit Officer (Research) and is now working at the Head Office of the N.S.W. Department of Agriculture. The Acting Officer-in-Charge of the Gosford laboratory is Mr. B. L. Wild.

Selected Publications of the Division

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

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* Not a member of the Division.

† No copies available for distribution.

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