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The retention of quality in packaged frozen foods depends largely on temperatures at each stage of storage and marketing. In this article the author discusses the importance of temperature control in retail display cabinets.

The Storage of Frozen

MOST frozen food cabinets contain an assortment of foods which are stored for widely varying periods of time and are affected in different ways by departures from correct storage practice. It is therefore difficult to provide optimum storage conditions for all foods in the cabinet. Conditions will also be related to what is practicable and economic in the manufacture and operation of the cabinet. For example, it may be desirable to store certain foods at −10°F, but the cost of providing a suitable cabinet and operating it at that temperature may be prohibitive, particularly if sales of these foods are relatively small.

STORAGE TEMPERATURES

It is beyond the scope of this article to review all published research on the effects of different storage temperatures on frozen foods, but examples will be quoted to show that different temperatures may have a marked effect on quality and storage life.

In experiments conducted by Lindquist, Dietrich, and Boggs (1950) frozen peas were stored at three temperatures, viz. −10, 0, and 10°F. Samples from storage for several periods at different temperatures were compared by tasting tests. It was found that storage at 10°F was unsatisfactory because flavour changes were soon noticeable, and texture and colour changes were apparent later. Even at 0°F slight flavour differences could be detected after 3 months, but no changes in colour and texture occurred until after 9 months.

Ascorbic acid (vitamin C) is often used as an index of other changes during storage. In studies on the storage of frozen broccoli and cauliflower at C.S.I.R.O., Homebush, it was found that broccoli lost about 10 per cent. of its ascorbic acid in 3 months at 0°F and about 30 per cent. in 12 months (Sykes and Tinsley, unpublished data 1952, 1955). With cauliflowers 7 per cent. ascorbic acid was lost after 3 months and about 27 per cent. after 12 months.

Such losses are greatly accelerated by storage at higher temperatures as Gortner *et al.* (1948) have shown at the New York Experiment Station. When stored at 10°F, 50–80 per cent. of the total ascorbic acid was lost from most vegetables after 12 months' storage. After storage at 0°F for 12 months all of the ascorbic acid was retained in peas and only one-third lost in other vegetables. Palatability changes ran parallel to losses in ascorbic acid.

Pierce *et al.* (1955) stored frozen strawberries and green beans at temperatures at 3-degree intervals between −3 and 12°F. They found that ascorbic acid was lost at a steady rate which was greatest at the higher temperatures. Strawberries stored at 6, 9, and 12°F showed a significant decrease in colour and flavour scores.

Packaged filleted fish shows a similar susceptibility to storage at temperatures above 0°F. Pottinger (1951) found that striped bass fillets remained in satisfactory condition for 8–9 months at −10 and 0°F. At 15°F, storage life was limited to 3 months. With mackerel, storage life at 15°F was only about 2 months compared with about 4 months at −10 and 0°F.

Fluctuations in temperatures have often been regarded as the cause of deterioration in frozen foods. Most of the published research on this subject indicates that, apart from the danger of increased desiccation in unpackaged or improperly packaged foods, the effects are mainly due to the time

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Foods in Display Cabinets

of actual exposure to higher temperatures. In the studies of Gortner *et al.* (1948) on frozen vegetables, quality changes and ascorbic acid losses at a temperature fluctuating between 0 and 20°F were similar to those occurring at 10°F. Hustrulid, Winter, and Noble (1949) stated that the effects of a fluctuating storage temperature, *per se*, on frozen foods are not important below 0°F for colour, flavour, texture, or nutritive value. The greater desiccation at these low temperatures did, however, emphasize the need for good packaging. Pottinger (1951) obtained similar results for frozen fish fillets and decided that the average storage temperature was generally the decisive factor in determining length of storage life.

PRACTICES IN THE UNITED STATES

The importance of the above findings is recognized by the leaders of the frozen food industry in the United States. McCoy (1954), Frigidaire Division, General Motors Corporation, has used the following words to emphasize the need to keep cabinet temperatures down to 0°F: "There is an unfortunate tendency on the part of some merchandisers of frozen foods to think that 0°F is not necessary. Cabinets should carry temperatures close to 0°F or below if possible . . . . . When frozen food is stored at temperatures around 15°F it should not be stored more than a few days to avoid loss of quality". Dykstra (1954), Manager of the Birds Eye Laboratories, New York, dealt with the same problem in these words: "Since time is involved, it might appear sensible to consider temperatures higher than 0°F for the shorter phases of the distribution cycle, such as transportation, order assembly and delivery, and retailing. However, we must keep in mind that exposures are additive in effect. Therefore concessions in temperatures are not considered advisable". Reporting on a 2-year survey of storage and distribution systems the speaker said: "Furthermore, the results of the survey show that, if an average temperature of 0°F is maintained, certain percentages of product will be exposed unintentionally to higher temperatures. A higher average temperature will expose a greater amount of product to those undesirable levels. In fact, some small amount will be exposed in a temperature zone where actual spoilage can occur". Nickerson (1956), in an address to operators of supermarkets, also pointed out that when frozen foods are stored above 0°F they are deteriorating at a faster rate than is desirable from the sales standpoint.

OPERATION OF CABINETS

In order to hold frozen foods in refrigerated shop cabinets for the periods normally required before selling, an air temperature of 0 to 5°F should be maintained throughout the greater part of the storage space.

In self-service stores it is not uncommon to find temperatures in open-top cabinets highest in the upper part. If this is so, the temperature of the packages in the top layer should not be allowed to exceed 10°F. Most frozen foods should not soften appreciably at this temperature and, providing they remain at this temperature no longer than two weeks, they should not show any marked loss of quality. The normal turnover from the cabinet should ensure that packages do not remain in the top layer for longer than this period of time. In any case it cannot be too strongly emphasized that only the top layer of foods should be permitted to reach 10°F.

Checking Temperatures

Cabinet temperatures should be checked three times per day by placing the thermometer in two positions:

- In a central position, one foot from the top of the stack.
- One inch from the top of the stack and at the centre of the top layer of packages.

The thermometer in the first position should not read higher than 5°F and, preferably, nearer 0°F. The reading in the second position should not exceed 10°F.

About once each week the thermometer should be placed in the following positions in the cabinet:

- One foot from top of stack, one foot from inner wall on left hand side, and one foot from front inner wall.
- The same position relative to the wall on the right side.
- A central position, one foot from top of stack.

The readings, which give a picture of the temperature distribution in the cabinet, should be as near as possible to 0°F and not higher than 5°F.

The thermometer should also be placed in the top layer of the stack in positions similar to above, namely,

- One inch from top of stack, one foot from left-hand side wall, and one foot from front wall.
- The same position relative to the wall on the right side.
- One inch from top of stack at the centre of the top layer.

For satisfactory operation, the temperatures in the top layer should not be above 10°F.

The bulb of the thermometer should be sheathed with heat-insulating material. It may be fitted, neatly but not tightly, into a plug of cork, so that the bulb is surrounded with a layer of cork ⅛ in. thick. Another method is to neatly wind stout string around the bulb. The purpose of the sheath is to enable the operator to remove the thermometer from the cabinet and observe the cabinet temperature before the reading alters significantly. If it is practicable to read the thermometer without removing it from the cabinet, the bulb need not be insulated. The thermometer should always be placed in an air space between packages and be left at least 30 min before reading.

Some Pitfalls

A writer in *Quick Frozen Foods* (Anon. 1955) has listed eight pitfalls to avoid in handling frozen foods. His sound practical advice is set out below.

Thawing.—Rush deliveries into zero storage. Don't let frozen foods stand outdoors or on store floor. Re-freezing thawed foods hurts quality, reduces nutritional value, destroys taste appeal, and loses customers.

Temperature.—Frozen foods require zero or lower temperature. Check cabinet three times daily—at opening, noon, and closing—to make sure that temperature is maintained at or below 0°F.

Frost.—Customers won't buy frost-covered packages, so avoid having dead stock. Sell it before frost gets in. Rotate when restocking. Move old packages to front of case and on top of new.

Packages.—Damaged packages don't sell. Glance at every package when rotating cabinet stock. Watch for any flaws. Is a package torn, crushed, frost-covered, wet, bulgy, crunchy, soft, or stuck to another package? If so it is unfit for sale; most customers won't buy such packages. Get rid of them.

Over-stocking.—The plate-line near the top of the cabinet's interior is the danger line. Frozen foods defrost when stacked above that line. Maintain full displays but STOP at the plate-line.

Crowding.—Frozen foods need air circulation. Give the cold air within the cabinet a path for circulation. When stocking leave a small space behind the front glass, at the sides, and in front of the rear wall. Make this space too narrow for extra packages to be jammed into it.

Pricing.—Check price slides when restocking to make sure that correct prices show, and that the slide price corresponds with the figure stamped on package. Make sure that every slide is near the proper item.

Untidiness.—Messy displays lose sales. Customers won't hunt for what they can't see. Orderly displays promote impulse sales. Only a moment is needed to put jumbled packages back in their proper rows. Attend to the frozen foods cabinet throughout the day. Keep it orderly and build sales.

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Glycogen and Hydrogen Ion Concentrations in Sheep Muscle

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Dr. M. N. Moorjani worked at the Division of Food Preservation and Transport, Homebush, as a Senior Fellow under the Colombo Plan in 1955–56, and devoted part of his time to an investigation on the distribution of glycogen and hydrogen ion concentrations in sheep muscle.

WHILE the post-mortem chemical changes in the muscles of bovines have been extensively studied, there are few data available on such changes with sheep.

Preliminary investigations, reported here, have been carried out at the Homebush Laboratory of the C.S.I.R.O. Division of Food Preservation and Transport and will be continued by the staff at the Division's Meat Research Laboratory, Brisbane.

The distribution of glycogen concentrations and pH values along the length of the eye muscle (longissimus dorsi) were determined in seven sheep. It was found that the initial glycogen values (1000 to 1200 mg per 100 g of muscle) and the ultimate pH values (5·5 to 5·8) were similar to those found in the l. dorsi muscle of normal beef animals.

There were no significant differences in the initial glycogen concentrations or in ultimate pH values at different positions along the muscle.

Measurements of the glycogen concentrations and pH values at intervals during the course of rigor mortis revealed that a part of the glycogen was disappearing without the corresponding decrease in pH value which would be expected from the anaerobic conversion of glycogen into lactic acid. For instance, when the muscles were stored after death for 24 hr at 0°C, the residual glycogen concentrations were in the range 176–300 mg per 100 g, while the pH values were 5·6–6·0. Subsequent storage of the muscles at 20°C for 24 hr reduced the glycogen concentrations to 0–23 mg per 100 g, but the average fall in pH values was only 0·15 unit. If all the glycogen which had disappeared had been converted to lactic acid, a fall of 0·65 unit of pH would have been expected. This discrepancy can probably be explained by the results of recent work by Sharp* at the Low Temperature Research Station, Cambridge. He has shown that muscle amylase converts part of the glycogen, post-mortem, to free reducing sugars.

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* See *Rep. Fd. Invest. Bd., Lond.* **1954**: 29, 31.

This paper, under the title "Some observations on rail transport of frozen foods with special reference to rises in temperature due to loading conditions", was presented to the 9th International Congress of Refrigeration in Paris in 1955. It is reproduced here with the kind permission of the Director of the International Institute of Refrigeration.

Rail Tranosport of Frozen Foods —

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IN Australia, close control of temperature in frozen cargoes is most critical where the cargo comprises frozen meat for export or packaged quick-frozen vegetables and fruit. Most journeys with such cargoes are fairly short, less than 48 hr, and there is no great difficulty in providing cars which will maintain satisfactory average temperatures. Consequently in most of our experiments with frozen goods attention has been concentrated on the maximum cargo temperatures and the effect of loading conditions.

CARGOES OF QUICK-FROZEN PEAS

Two types of car have been studied, namely, a 40-ft roof tank car similar to the well-known Canadian pattern and an end bunker car of similar size with four small supplementary roof tanks (holding ½ ton ice in all) which are mounted opposite the doorways. The end bunkers hold 1·2 tons of ice each. The cars were always pre-cooled using 25–30 lb of salt per 100 lb ice and the same salt concentration was used in re-icing after loading. There was no re-icing *en route* on journeys not exceeding 40 hr.

Measurements were made in retail packs of frozen peas which consisted of 48 12-oz packets in a fibre-board master carton. Thermocouples were used for the temperature measurements. In order to obtain measures of maximum cargo temperatures thermocouples were placed in extreme corner packets as well as at the more usual position at the centre of a master carton. Each thermocouple was inserted near the centre of the block of peas in a small packet before freezing and then frozen in.

In one series of experiments the cartons of peas were conveyed from the store along an enclosed conveyor. The doorway of the car was closed by a wooden framework covered with canvas, the only opening being a flap cut in the canvas, which was just large enough to allow cartons of peas to pass through on the conveyor.

The roof tank cars have side wall flues and the cartons formed a solid stack except for a vertical gap 12–20 in. wide across the car opposite the doors. Floor racks were used in both types of car. The end bunker cars have no side wall flues, and wall racks were used to keep the stacks approximately 4 in. away from the side walls. Loading took approximately 75 min.

Temperature histories at some of the more interesting positions in two of these experiments are shown in Figure 1. No temperatures in the inner parts of the stack are quoted; these did not change significantly either during loading or during the journey of approximately 24 hr. The average outside air temperature during the journey was 66°F.

In another experiment, from a place where it was necessary to transport the peas a short distance by road from the store to the railway, the temperature rises in the outer parts of the stack were generally similar to those shown in Figure 1, but there was an average rise in temperature of 4·5°F during loading over the whole cargo. This rise varied by about 3°F, depending on the position of the carton on the road vehicles.

Temperature Rises during Loading

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CARGOES OF FROZEN MEAT

Some extracts from the records of one series of measurements with beef for export are shown in Figure 2. The temperatures quoted were measured just below the surface of the meat.

These data were obtained in an old type of end bunker car which is fairly well insulated (heat leakage coefficient 130 B.t.u./(°F hr)) but has rather small bunkers. Approximately 10 per cent. salt was added to the ice for pre-cooling, but, as a rule, there was little or no salt left by the time loading began. Thus, during the journey, the vehicles were operating practically as insulated boxes without any coolers.

The meat was loaded from a store at approximately 1·5°F. Loading was very fast, taking only 15–20 min per car. The cars being loaded were in a covered space close to the unloading hatch in the wall of the cold store. The doors of the car on the loading side were fully open during loading. Hind quarters of beef were stowed vertically in the cars with the shanks on the floor, so that the thinner parts of the quarters were near the top of the vehicle. Crops were stacked horizontally and therefore more closely: with

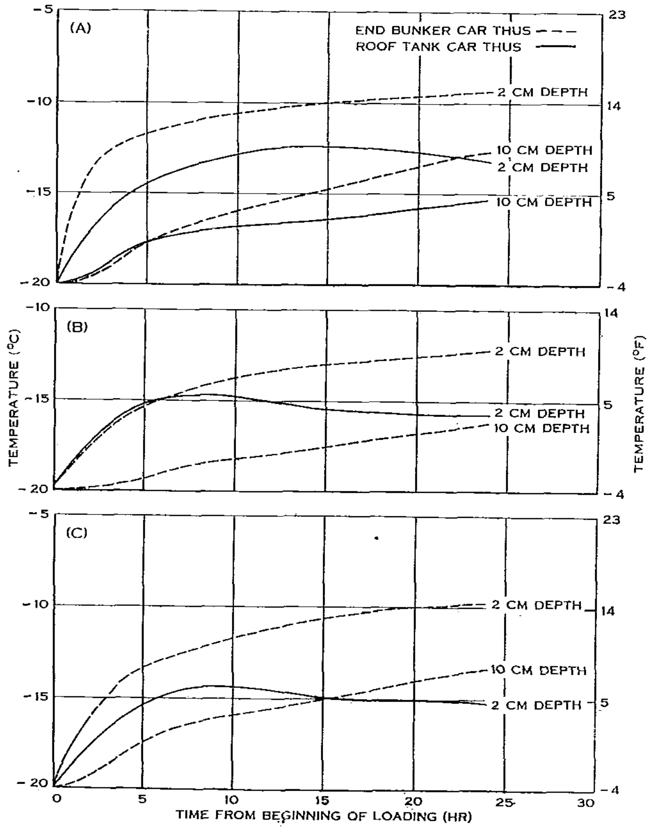

Fig. 1.—Temperatures in cartons of frozen peas.

A, On top corner of stack against end wall—very good loading conditions.

B, At the centre of top of stack.

C, On top edge of load, half way between doors and end of car.

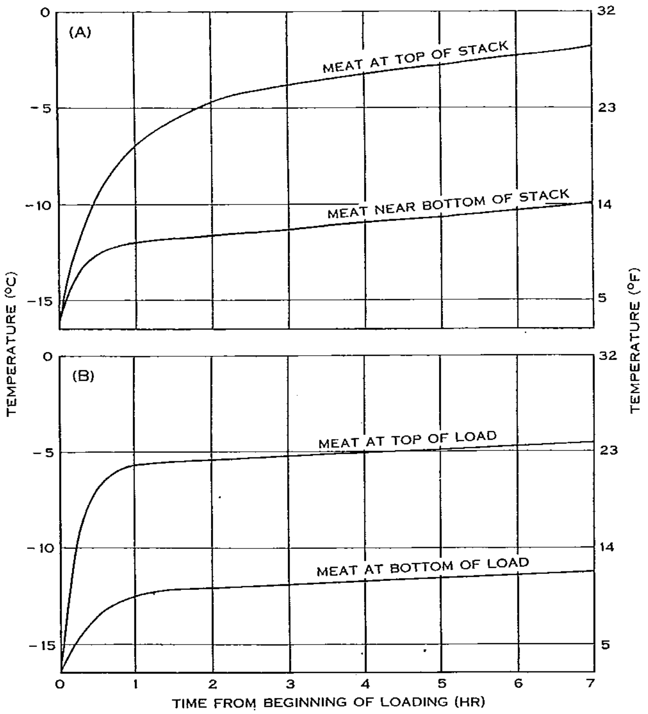

Fig. 2.—Temperatures in frozen beef in pre-cooled insulated vehicle. Outside temperature 90°F.

A, Frozen hind quarters of beef stowed vertically with thin parts upwards.

B, Frozen beef crops (fore-quarters) stowed horizontally.

these the thermal capacity was evenly distributed through the stack.

The outside temperature during the journey averaged 90°F and the relative humidity was also high.

DISCUSSION

It will be seen in the graphs shown in Figures 1 and 2 that there were large rises in cargo temperature at the top of the stack during and shortly after loading. The interpretation of the data is simplest for the roof tank cars which have cold ceilings (at 0°F or a little lower in moving cars). Thus, in these cars the whole of this initial rise can be attributed to loading conditions.

The results graphed in Figure 1 were obtained with very good loading conditions which have already been described. Nevertheless, the temperature of an extreme corner packet of frozen peas rose to a maximum of 11°F some hours after loading. It cooled slowly during the remainder of the journey. Packets of peas in other positions on the top of the load, either remote from the side of the car or loaded substantially later than the extreme corner of the stack, warmed, on the average, to approximately 5°F and then cooled slowly during the rest of the journey. Temperatures at the centres of master cartons, which are the ones usually quoted, all remained below 5°F.

Thus, in these cars, with great care taken to restrict warming during loading, there were temperature rises on the extreme top of the stack ranging from 9 to 15°F. These were partly recovered later in the journey. The average temperature rise throughout the whole stack due to loading was very small. No doubt the "loading" losses would have been much greater if special precautions had not been taken to restrict them.

The data for an end bunker car in Figure 1 show much larger temperature rises in the top of the stack than in the roof tank car and, moreover, there was no recovery of the loading losses later in the journey. An ordinary end bunker car has, inherently, a relatively warm ceiling and relatively inefficient cooling of the top of the stack by the ice and salt in the bunkers. Consequently, part of the apparent loading losses in these cars is not properly attributable to loading conditions. This is discussed further below.

The results for beef shown in Figure 2 were obtained under less satisfactory loading conditions, but they were, nevertheless, better than those obtained at many works in Australia and elsewhere. It will be seen that the temperature rises with these cargoes were much larger than those shown in Figure 1. As usual, the greatest rises in temperature were at the top of the load and these were much greater in hind quarters than in crops. This was no doubt because the thermal capacity of the thin parts of hind quarters at the top of the load was much less than that of the top layer of crops.

There is virtually no flow of cold air over the face of the stack against an end wall in these roof tank cars and there is not much cooling of the top of the stack in the end bunker cars. Consequently temperature histories in these positions, assuming no loading losses, may be calculated from solutions of the equation of conduction of heat. We treat a stack of frozen peas as a semi-infinite solid of thermal conductivity 0·42 kcal/(m hr °C) (Smith, Ede, and Gane 1952) and thermal diffusivity 0·0014 m^2/hr (Short 1944), and we assume that the rate of heat transfer between the outer surface of the car and the surface of the stack is 0·072 B.t.u./(ft^2 hr °F). (It is known that this value is appropriate for the relevant parts of the vehicles being considered, although their average conductance is higher.) Theoretical curves calculated with these assumptions are shown in Figure 3 together with corresponding experimental curves. Among the interesting points revealed by these curves are:

- There was a significant loading loss (2·5°F approx.) in a case against the end wall of the roof tank car. This was, no doubt, due to incomplete pre-cooling. The car temperature became steady at 16°F before loading. (Roof tanks filled with ice and salt are less efficient coolers in stationary cars than in moving ones.)
- The apparent loading loss near the centre of the top of the stack in the end bunker car was approximately 6·5°F. This will be an underestimate because there was some flow of cold air over the stack.
- Temperatures measured at a depth of 2 in. would be expected to be about 1°F below the true maximum cargo temperatures in the later stages of these journeys, and they would differ more in the early stages.
- Rises of about 9°F in the first 24 hr are inevitable on any outer face of the stack which does not have a flow of cooled air over it.

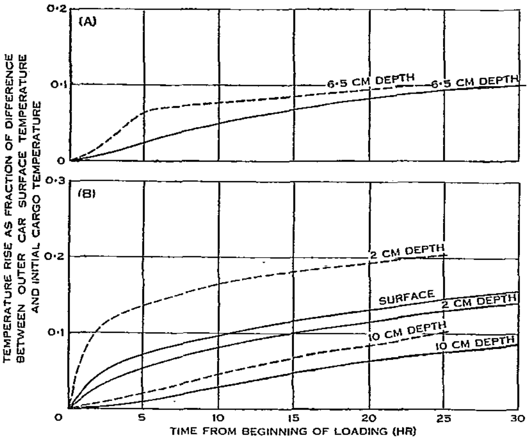

Fig. 3.—Temperatures in cartons of frozen peas.
--- *Measured temperatures.* —— *Calculated temperature histories assuming no loading losses.*

A, In centre of face of stack against end wall.

B, At centre of top of stack in end bunker car loaded under very good conditions.

CONCLUSIONS

(1) Temperature rises due to loading conditions will usually be the main factor governing the maximum temperature in frozen foods on fairly short journeys, even when elaborate precautions are taken to restrict loading losses.

(2) Loading losses are usually greatest on the top of the stack. They may be partly recovered during the journey in roof tank cars and, presumably, in fan cars, but not in ordinary end bunker cars.

(3) For close control of maximum cargo temperatures it seems essential to have a flow of cooled air over every face of the stack.

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THE LABORATORY EXAMINATION OF CANNED FOODS—XII

Acidity and

Earlier articles in this series appeared in **C.S.I.R.O. Food Preservation Quarterly,** *Vol. 13 (1953), pp. 3–8, 21–31; Vol. 14 (1954), pp. 8–18, 26–31, 46–52, 74–6; Vol. 15 (1955), pp. 28–32, 52–7, 72–7; Vol. 16 (1956), pp. 7–10; and Vol. 17 (1957), pp. 11–14.*

ACIDITY in foodstuffs may be expressed in two different ways: in terms of total or titratable acidity or in terms of pH, which may be regarded as a measure of the strength of the acidity.

TITRATABLE ACIDITY

The titratable acidity is measured by the amount of a standard alkali (usually 0·1N) required to neutralize a food sample to the point of colour change of an indicator, which is not necessarily at true neutrality. The indicator generally used in the titration of foods is phenolphthalein which shows an endpoint at pH 8·1.

From the result of the titration it is customary to calculate the titratable acidity as a percentage in terms of an appropriate acid which is usually the acid present in the food in greatest amount. The acid chosen as the basis for calculation must always be stated when recording the titratable acidity. In liquid products the acidity is generally expressed as a weight/volume percentage, and in solid and semi-solid products as a weight/weight percentage.

Procedures recommended for determining titratable acidity in some specific canned foods are outlined below (cf. Royal Australian Chemical Institute 1952).

Fruit Juices

Take 10 ml of juice and dilute with 100 ml of distilled water. Add 0·3 ml of phenolphthalein solution (1 per cent. in 95 per cent. ethanol). Titrate with 0·1N sodium hydroxide to a permanent light pink colour.

In highly coloured solutions the end-point is difficult to detect. The most satisfactory procedure is then an electrometric titration to pH 8·1 using a glass electrode (see below). In the absence of facilities for electrometric titration, a number of alternative procedures have been suggested. An external indicator such as a powder consisting of 1 part phenolphthalein and 100 parts powdered potassium sulphate may be used on a spot tile. In a procedure suggested by the Association of Official Agricultural Chemists (1955*a*), when the titration is approaching the end-point, a 2 or 3 ml portion is withdrawn into a small beaker and diluted to 20 ml. At this dilution the phenolphthalein pink is more easily seen. For acidity estimations on apple juice and cider, Burroughs (1946) recommends as an indicator a mixture of bromthymol blue and phenol red, which changes from blue-green to purple between pH 7·4 and 8·0 and is grey at the end-point. Kottász (1955) suggests the chemiluminescent indicator, lucigenin (dimethyldiacridilium nitrate), for titrations of highly coloured fruit products. The titration is carried out in a dark room and the end-point is indicated by the appearance of green chemiluminescence at pH 8·5 in the presence of hydrogen peroxide and alcohol.

From the result of the titration the acidity is calculated as a percentage in terms of the appropriate acid as follows:

Apple juice, apple and pear juice, apple and blackcurrant juice: malic acid

Citrus juices: citric acid (anhydrous)

Pineapple juice: citric acid (anhydrous).

The table on p. 31 sets out conversion factors for a number of acids commonly occurring in foods.

Critical comments on the procedures described, and suggestions for modified or alternative methods found to be useful in practice, will be welcomed.

pH Values

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Pickles

From mixed pickles and pickled onions take 10 ml of the covering liquor. From mustard pickles take 10 g of a comminuted sample representative of the product. Dilute with warm water and titrate with 0·1N sodium hydroxide to the phenolphthalein end-point. Highly coloured products such as mustard pickles must be considerably diluted to give a distinct end-point using a relatively large amount of indicator.

In vinegar, vinegar pickles, sauces, and chutneys the percentage acidity is calculated as acetic acid. The acidity of vinegar is sometimes expressed in terms of grain. In American practice 1 per cent. acetic acid = 10 grain, but in British practice evidently 1 per cent. acetic acid = 4 grain (Poultney 1949).

Tomato Sauce, Worcestershire Sauce

Weigh out a sample of 12·00 g, make up to 100 ml with distilled water, and filter. Titrate 25 ml of the filtrate with 0·1N sodium hydroxide to the phenolphthalein end-point. Divide the result by five to obtain directly the percentage acidity as grams of acetic acid/100 g.

Sauerkraut

Take 10 ml of the liquid portion following a drained weight determination, titrate with 0·1N sodium hydroxide to the phenolphthalein end-point, and calculate the acidity as lactic acid.

Conversion Factors for Food Acids

Titratable acidity (%) = conversion factor × No. of ml of 0·1N alkali to titrate 10·0 ml sample of food

Acid	Formula	Molecular Weight	Equivalent Weight	Conversion Factor
Acetic	$HC_2H_3O_2$	60·03	60·03	0·060
Citric (anhydrous)	$H_3C_6H_5O_7$	192·06	64·02	0·064
Citric (hydrated)	$H_3C_6H_5O_7 . H_2O$	210·08	70·03	0·070
Lactic	$HC_3H_5O_3$	90·05	90·05	0·090
Malic	$H_2C_4H_4O_5$	134·05	67·03	0·067
Oleic	$HC_{18}H_{33}O_2$	282·39	282·39	0·282
Tartaric	$H_2C_4H_4O_6$	150·05	75·03	0·075

HYDROGEN ION CONCENTRATION

In many examinations of canned foods, a measure is required not of the total acidity but of the intensity of the acidity, which depends upon the concentration of hydrogen ions. In foods, this concentration is very low. Thus, in an acid fruit product the concentration of hydrogen ions may be about 1 gram in 1000 (10^3) litres; in canned vegetables it ranges between 1 gram in 100,000 (10^5) and 1 gram in 1,000,000 (10^6) litres; and in neutral water it is 1 gram in 10,000,000 (10^7) litres. Expressions involving these very large numbers are avoided by the use of the pH notation devised by Sorenson in 1909. Hydrogen ion concentrations are represented by the indices of the powers of 10 shown above, which are then called pH units. Thus the fruit pack has a hydrogen ion concentration expressed as pH 3, canned vegetables have pH values between 5 and 6, and neutrality is represented by pH 7. The higher the pH, the lower the acidity and vice versa. Solutions having pH values higher than 7 are alkaline in reaction.

Putting what has been said in mathematical terms:

$$\text{pH} = -\log_{10} C_H,$$

or more precisely, in line with modern theory,

$$\text{pH} = -\log_{10} a_H,$$

where C_H is the hydrogen ion concentration, and a_H is the hydrogen ion activity as affected by all other associated ions. In fact, however, neither C_H nor a_H can be determined. Therefore in practice pH is defined in terms of arbitrary standard buffer solutions such as 0·05M potassium hydrogen phthalate which has pH 4·00 at 20°C (British Standards Institution 1950; National Bureau of Standards 1950). For full discussion of the modern theory and practice of pH determination the reader is referred to Bates (1954) and Small (1954).

The table on page 33 shows the composition and pH values at several temperatures of some standard buffers covering the range of pH in foods (A.O.A.C. 1955*b*). Standard buffer solutions should not be kept longer than 2 months. To avoid mould growth about 1 gram thymol per litre should be added. The buffer is shaken at intervals until nearly all the thymol dissolves, then filtered and kept in a stoppered bottle, preferably of Pyrex glass or polyethylene.

The pH of a food sample is determined by measuring the difference between its hydrogen ion e.m.f. (E) and the e.m.f. (E_S) of a standard buffer (pH$_S$).

Thus in the cell:

H_2; solution| sat.KCl; reference electrode

$$\text{pH} - \text{pH}_S = \frac{E-E_S}{2{\cdot}3026\, RT/F},$$

where R is the gas constant, T is the absolute temperature, and F is Faraday's constant.

The hydrogen electrode is the primary indicator for hydrogen ions but it is now usually replaced for practical pH determinations by a glass membrane which responds as a hydrogen ion electrode. The reference electrode is generally a saturated calomel half-cell. The cell for pH determinations thus becomes:

Glass || solution | sat.KCl, Hg_2Cl_2; Hg.

When saturated potassium chloride is used in the salt bridge the liquid junction potential is negligible.

It is then necessary to provide electrical equipment of sufficient sensitivity to measure, with an accuracy of at least ± 2 mV, the e.m.f. developed in the cell. There are available many commercial models of pH meter which provide the essential equipment for pH measurements. The glass electrode, a dip-type calomel electrode, and a thermometer are usually mounted so that all three are introduced into the test sample together. Owing to the high resistance of the glass membrane the current passing is minute and requires amplification in a vacuum-tube electrometer circuit before it is detectable on the galvanometer. This galvanometer may show a direct deflection on a scale calibrated in pH units or it may be a null indicator in a potentiometer circuit in which the slide wire is calibrated in pH units. The power for the pH meter may be supplied from batteries or from A.C. mains. In the latter case suitable devices must be incorporated to stabilize the voltage.

Each type of instrument differs slightly in operating details and full instructions are supplied by manufacturers. However, the following practical points may be emphasized in connection with pH measurements on canned foods.

Standard Buffer Solutions

Composition	pH Value		
	20°C	25°C	30°C
KH tartrate, 0·034M (approx.): saturate at room temp. and filter	—	3·56	3·55
KH phthalate, 0·05M: 10·21 g/l (dried 1 hr at 105°C)	4·00	4·01	4·01
KH_2PO_4, 0·025M: 3·40 g/l, and Na_2HPO_4, 0·025M: 3·55 g/l (dried 2 hr at 110–130°C)	6·88	6·86	6·85
Borax ($Na_2B_4O_7.10H_2O$), 0·01M: 3·81 g/l (not oven-dried). Use CO_2-free water	9·22	9·18	9·14

Sampling

The sample of a canned food taken for pH determination must be homogeneous, representative of the pack, and sufficiently fluid to permit intimate contact with the electrodes. Most glass electrodes are robust enough to enter viscous or semi-solid foods. Liquid foods are sampled directly. The syrup or brine from fruit or vegetable packs provides a suitable sample when the products have been canned for several weeks. In freshly canned packs the solid and liquid portions show significant differences in pH and are sampled separately or as a composite sample mashed together in the correct proportions. Electric blenders are useful for converting canned foods to purées for pH measurements. More solid products such as meats may require the addition of a little distilled water. Most foods are sufficiently well buffered to permit the addition of a little water without appreciably altering the pH.

Standardization

The pH meter should always be standardized with two standard buffers bracketing the pH of the unknown sample. The following procedure is suggested.

Standardize the instrument at the known pH of one standard buffer. Repeat with additional portions of the buffer until the instrument remains in balance (within ±0·02 pH unit) for two successive portions. Wash the electrodes and vessel three times with a jet of distilled water and touch with clean absorbent tissue or cotton wool. Form a fresh potassium chloride film if the salt bridge is not of the continuous-flow type. Now insert a sample of the second standard buffer and read the pH. Repeat with additional portions until successive readings agree within ±0·02 pH unit. The instrument may be regarded as operating satisfactorily if the pH reading for the second standard is within ±0·05 unit of the known pH. The pH meter should be standardized several times daily when it is in constant use, and always before each series of readings when in intermittent use.

Test Procedure

Again wash the electrodes thoroughly, dry, and form a fresh liquid junction. Insert a sample of the food under test and read the pH. Make certain that the sensitive membrane of the glass electrode is immersed in the sample and thoroughly wet by it. Repeat with further portions until the pH values of two successive portions agree within ±0·02 pH unit. Do not allow potassium chloride draining from the liquid junction to accumulate in the samples or standardizing buffers.

Temperature Control

It is important to emphasize that the pH meter measures a difference in pH between a standard buffer and a test solution, both of which must be at the same temperature. The temperature compensation provided on most pH meters corrects only for differences between the temperatures of the sample and the temperature at which the pH scale of the instrument was calibrated. A reasonable working rule is that the difference in temperature between standard buffers and test samples should not be more than 3°C.

Accuracy

The pH values of canned foods should be reported to the nearest 0·1 unit with a probable limit of error of ±0·05 unit.

SIGNIFICANCE OF pH AND ACIDITY

Processing

The heat process required to achieve commercial sterility in a canned food is determined to a large extent by its pH value. Canned foods are classified into four broad groups according to pH, thus: low-acid foods, pH 5·5 and higher; medium-acid foods, pH 4·5–5·5; acid foods, pH 3·5–4·5; and high-acid foods, pH 3·5 and lower. The important dividing line is pH 4·5, a critical level below which practically all spore-forming spoilage bacteria are unable to grow. Therefore, products below pH 4·5 require only a pasteurizing process, usually at 212°F, to destroy vegetative organisms. Products above pH 4·5 require a process, usually at 240–250°F, severe enough to destroy heat-resistant spores. Some canned foods are acidified to bring the pH within the range of the acid group, e.g. pawpaws, bananas, jack fruit, figs, sweet peppers, and some varieties of pears.

Significant changes in the pH values of canned foods may occur during heat processing (Adam 1934, 1939). For instance in some low-acid and medium-acid packs a fall in pH of 0·5–1·5 units is observed. During storage also, particularly incubator storage, a reduction in pH is commonly recorded.

Spoilage

An abnormally low or high pH in a canned food may be a useful indication of spoilage. "Flat sour" spoilage is most readily detected, in the absence of bacteriological tests, by a fall in pH.

Palatability

A common index of palatability in citrus and pineapple juices is the sugar/acid ratio or Brix/acid ratio, which is given by:

$$\frac{\text{Per cent. total soluble solids by wt.}}{\text{Per cent. acid by wt.}}$$

The sour taste in foods is, however, a function of the two variables total acidity and pH.

Pectin Gels

Control of pH is important in the manufacture of jams, jellies, and marmalades, in which a desirable consistency depends on the formation of a pectin gel. The optimum pH range for the gelling of pectin is pH 3·0–3·3.

Preservatives

The efficiency of the common preservatives, sulphur dioxide and sodium benzoate, is greatly influenced by the pH of the medium. In general neither preservative is useful above pH 3·5 and the inhibitory effect on microbial growth increases greatly at lower pH values.

Pickled Vegetables

Acidity determinations are required in the control of pickle fermentations, e.g. in cucumber and sauerkraut pickling, where the acid produced is mainly lactic. To permit the canning of sauerkraut as a pasteurized pack the final product should contain at least 1 per cent. acid.

Acidity Tables

Extensive lists of the pH values of canned foods are available (American Can Co. 1948; Goldman 1949; Adam 1950; Townsend *et al.* 1954). The last- named authors and Money and Christian (1950) also record ranges of titratable acidity in a large number of fruit products.

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NEWS from the Division of Food Preservation and Transport

PERSONAL

Mr. B. V. Chandler, Senior Research Officer in the Fruit Products and Canning Section leaves Australia in June, 1957, to take a short-term appointment on the staff of the University of California at Berkeley, U.S.A. Mr. Chandler will work for 12 months or so with Dr. Gordon MacKinney in the Department of Food Technology, College of Agriculture, mainly on a project concerning the biosynthesis of carotenoid pigments.

Mr. J. J. Macfarlane, a Research Officer in the Division's Physical Chemistry Unit, has been granted a Divisional Overseas Studentship, which he has taken up at the Low Temperature Research Station, Cambridge. Mr. Macfarlane has joined a team led by Dr. R. S. Hannan, which is studying the effects of ionizing radiations on food, but he will spend portion of the 2-year studentship at other institutions in Britain which are working in the same or related fields. Mr. Macfarlane left Australia by air on May 26, 1957.

Mr. Amara Prachankadee, a Scientific Officer in the Division of Biological Science, Ministry of Industry, Bangkok (Thailand), made his headquarters in the Homebush laboratories of the Division of Food Preservation and Transport during a sojourn in Australia from January to April 1957. Mr. Prachankadee was brought to Australia by the Food and Agriculture Organization of the United Nations, under its Technical Assistance Programme, to study a number of aspects of food technology. In addition to the laboratories of the Division of Food Preservation, Mr. Prachankadee visited C.S.I.R.O. laboratories in Hobart (Tasmania), Merbein (Victoria), and Brisbane (Queensland). Mr. Prachankadee left Australia by air on April 17, 1957.

PUBLICATIONS BY STAFF

A Histological Study of the Development of Superficial Scald in Granny Smith Apples. *Joan M. Bain. J. Hort. Sci. 31: 234–8 (1956).*

Superficial scald first appears as light brown patches on the skin of apples after several months' storage at low temperature. Its extent and severity vary with the season, the maturity of the fruit, and the length of storage. Histological investigations were carried out during two seasons with the susceptible variety Granny Smith to examine changes in the cells beneath the epidermis of the fruit before the appearance of the macroscopic symptoms of scald, and to follow tissue changes as they developed.

The development of scald, during or after storage at low temperature, is due to the progressive browning of the contents of the cells of the hypodermis. In slightly scalded fruit, contents of the outer hypodermal cells are light brown, while the inner adjacent cells appear to be normal. With increasing severity of the disorder, the light brown colouring of the skin deepens and the browning of the cells increases in intensity and extends through the five or six layers of the hypodermis. The epidermal cells are not affected unless the disorder is very severe; when this occurs, groups of epidermal cells may become brown.

In severely scalded fruit, the affected cells of the hypodermis collapse in a radial direction, so that the brown area becomes sunken. The cells of the outer cortex also become distorted but the shape of the epidermal cells is not affected.

Cell browning is associated with cells containing numerous chloroplasts but does not appear to be caused by disorganization of these bodies.

There was no evidence of any histological changes in the tissue prior to the appearance of the macroscopic symptoms of superficial scald, except for a slight difference in intensity of staining with methylene blue.

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SOME ENGINEERING ASPECTS OF FRUIT AND VEGETABLE HANDLING. *E. W. Hicks. Food Tech. Aust. 8: 655, 657, 659, 661, 669 (1956).*

The writer points out that bringing fruit and vegetables from grower to consumer is primarily a job in materials handling, but it is complicated by their perishable nature and the need to keep them at low temperatures to maintain their quality. He discusses the merits, under Australian conditions, of ventilated rail cars, mechanically refrigerated cars, and those refrigerated by ice. Pre-cooling including the new vacuum cooling method for leafy vegetables is also discussed.

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CHROMATOGRAPHY OF DINITROPHENYLHYDRAZONES AND DINITROBENZOATES. *F. E. Huelin and B. H. Kennett. Chem & Ind. 1956: 715.*

The production of volatile substances by apples is being investigated, as there is evidence that such compounds are concerned in the storage disorder superficial scald. This paper is concerned with the separation of volatile alcohols, aldehydes, and ketones with a view to their identification and determination.

Copies of the papers mentioned above may be obtained from the Librarian, Division of Food Preservation and Transport, Private Bag, P.O., Homebush, N.S.W. (Telephone: UM 8431, UM 6782.)

FOOD SCIENCE ABSTRACTS

TUNNEL DEHYDRATORS FOR FRUITS AND VEGETABLES. *P. W. Kilpatrick, E. Lowe, and W. B. Van Arsdel. Adv. Food Res. 6: 313–72 (1955).*

This discussion of tunnel dehydrators, as used to dehydrate fruits and vegetables, is intended to provide a general introduction to the subject. It deals with the development of tunnel dehydrators; the different types ((1) longitudinal air circulation, with counterflow or parallel-flow, or combinations of the two, and (2) transverse air circulation); and the fans and blowers, heating systems, instrumentation, materials of construction, and trays and trucks, used in tunnel dehydrators. An account is given of some commercial dehydrators, and of the factors governing the selection of a dehydrator. The basic theory of dehydration is expounded, and is applied to the determination of optimum loads, proportion of air to be recirculated, internal temperature of products being dehydrated, etc. Operating procedures, and recent trends in dehydration are surveyed.

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The abstract in this section has been taken from Food Science Abstracts *with the kind permission of the Controller of Her Majesty's Stationery Office, London.*