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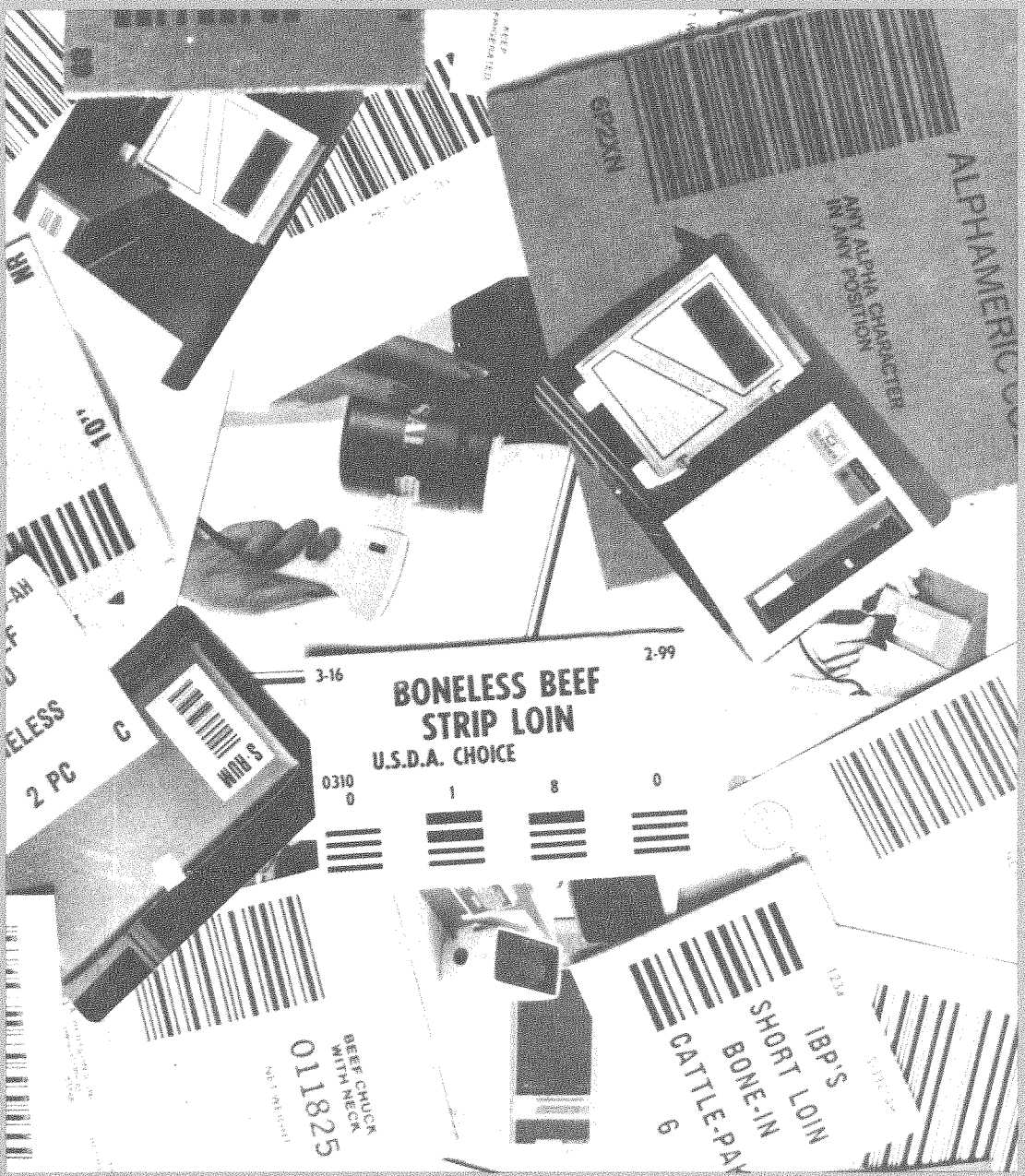

New Developments in the Australian Meat Industry

By B. Y. Johnson

CSIRO Division of Food Research, Cannon Hill, Qld, 4170.

In Australia, and in most other countries, the meat processing industry is diverse and fragmented comprising a wide range of meatworks owned by private and public companies, and governmental or semi-governmental authorities, in which daily production rates vary from a few cattle, pigs and sheep, to one thousand cattle and ten thousand or more smallstock. An abattoir located in a remote part of Australia may send all its production overseas as frozen boneless manufacturing beef in fibreboard cartons, while an abattoir situated in a capital city may sell all its production as chilled beef quarters to local trade.

In the last few years there have been substantial technological developments in the meat industry. It is widely recognized that if future escalation of production costs is to be contained, greater productivity and yields must be achieved. It is also recognized that Australian beef is often of very variable quality, and if optimum returns are to be realized, improved tenderness must be achieved.

This paper outlines some of the recent developments aimed at solving some of the industry's problems.

Tenderness

Electrical stimulation

If the temperature of freshly slaughtered meat falls below 10 °C before it is in *rigor*, it will toughen, and this may prompt complaints from the consumer. This toughening is called cold-shortening and the lower the temperature, the greater is the toughening.

If a muscle is quickly frozen before it is in *rigor*, the rigidity caused by freezing could prevent the muscle from shortening. However, if the meat is subsequently thawed rapidly, it will shorten and toughen considerably, and lose massive amounts of juice. This is called thaw-shortening.

Muscle already in *rigor*, however, will not cold- or thaw-shorten, regardless of the temperature at which it is held.

Toughening can be avoided by holding carcasses for several hours (conditioning) at an appropriate temperature above 10 °C before low temperature chilling or before freezing or by using electrical stimulation. Electrical stimulation is achieved by passing a pulsed electric current through each carcass soon after slaughter. This greatly increases the rate of the natural processes leading to *rigor mortis* and substantially reduces the ability of the muscle to shorten (and hence toughen) when cooled rapidly. This method has two potential benefits for processors (and consumers): tenderness is retained in carcasses which are rapidly chilled or frozen, and carcasses can be hot-boned i.e. cut down immediately after completion of dressing, without fear of the meat cold-shortening during chilling or freezing (important only for table meat cuts).

Electrical stimulation — also called accelerated conditioning — is widely used with lamb carcasses in New Zealand to avoid the delays of traditional conditioning which involves hanging the carcass at about 10 °C

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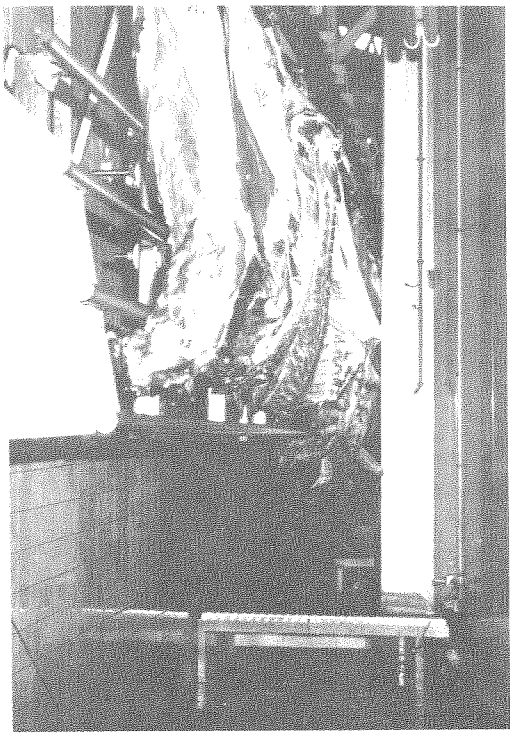

Fig. 1. High voltage stimulation of beef sides

for many hours. The method is now also an accepted part of beef handling procedures in Australian abattoirs. The advantages to the meat industry are well documented and substantiated by some 50 or more Australian slaughter-houses and abattoirs who are using electrical stimulation to achieve rapid conditioning.

Requirements for electrical stimulation systems vary considerably from works to works: small slaughterhouses could not justify automatic systems while existing works can often only find space to install such a system at a certain stage of dressing. Larger works would probably require an automated electrical stimulation system. Because of these varying needs, many different techniques or systems have been developed. The techniques described here are for beef cattle, and are not necessarily specifically applicable to stimulation of sheep carcasses.

Of tw- electrical stimulation systems developed by the Meat Research Laboratory of the Division of Food Research, CSIRO, the simplest is manually operated and is most suitable for smaller plants, killing up to a maximum of 200 cattle per day. This unit — the extra low voltage (ELV) rectal-to-nose stimulator — presently costs about $A2000. The other system — an automatic, high voltage (HV), on-the-rail stimulator — is considerably more expensive because safety requirements make it more complex. It must be tailored to each abattoir's requirements and is designed for large daily throughputs.

The ELV unit requires manual insertion and removal of the probes. This must be done within eight minutes of stunning. The unit is switched on after the insertion of the probes and reset for the next stimulation cycle. The HV system, which is suitable for high rates of kill, is fully automatic.

The maximum voltage of the ELV unit (32 volts RMS) is within the limit acceptable as extra-low voltage by Australian electrical supply authorities. The carcass and probe require no shielding. However, because electrical stimulation causes muscular contractions in the carcass it should not be worked on during low voltage stimulation.

The HV system (using voltages of 300–800V RMS) is completely shielded to minimize danger to personnel and is fully automatic.

HV stimulation systems require a greater capital investment (about $A20 000 installed) than do ELV systems, mainly because of the extra safety features required. However, compared with ELV systems, they are more effective, more time tolerant (allowing stimulation up to 60 minutes after stunning), and require no additional labour.

For effective stimulation, the HV electrodes must be located so that the current will pass, as nearly as is practical, through the entire carcass or side. The conveyor rail is the logical choice for one electrode (additional contacts will be required if insulating materials are used in the suspension trolley wheels).

Branding electrically stimulated meat. — Primal cuts from carcasses that have been effectively stimulated and conventionally chilled and boned will be more tender than meat that has been treated similarly but not stimulated. However, if stimulated meat is to be identified by a brand or mark implying a consistently more tender product, then there should be limitations placed on such identification to ensure the integrity of the

technique as a tenderness enhancement treatment is maintained.

Age-induced toughness is not affected by electrical stimulation. Only animals less than about 3½ years old are capable of consistently yielding tender meat, and it is not proper to use a description or mark for meat from older animals which implies consistent tenderness.

For various reasons, some forequarter muscles do not obtain any significant advantage from stimulation. Any marketing or branding that implies tenderness should therefore be restricted to hindquarter primal cuts and the cube roll.

Consistent tenderness cannot be guaranteed with stimulation followed by hot-boning. With an appropriate time delay between stimulation and hot-boning, tenderness only comparable with conventional unstimulated, chilled and boned meat can be expected.

Productivity

Accelerated processing of beef

Meat handling in modern abattoirs can be described as an 'interrupted flow' system. In a meatworks which debones the carcass for packing the meat into cartons, the overnight (or longer) chilling phase introduces a substantial delay in the flow of product.

Continuous flow processes are generally recognized as being more efficient than batch processes, and in times of increasing pressure to become more efficient, it is not surprising that the meat processing industry should seek to explore the possibilities of continuous flow. Accelerated processing of carcasses, commonly called hot-boning, is such a possibility, and is being commercially evaluated.

The basic concept of accelerated processing is that killing, dressing, deboning and packing of the meat is done in a single working day. The system offers several advantages:

- Because the meat on the carcass occupies only about 5% of the space which is actually devoted to chilling carcasses in the Australian meat industry, a very large reduction in the amount of refrigerated space required for meat chilling is possible. In addition to this, because about 30% of a beef carcass consists of unwanted bones and trimmings, the removal of the meat from the carcass before chilling reduces the refrigeration energy requirement by about the same amount.
- During the chilling of carcasses in the conventional way, an average of about 2.4% of the carcass weight is lost by evaporation of moisture from the meat. If hot-boning were undertaken and the product were quickly wrapped and sealed against moisture loss, a good deal of this yield deficit would be avoided. Indeed, semi-commercial trials in Australia have indicated that for manufacturing meat, a 1% improvement in yield (to the bone in weight) can be obtained.
- By accomplishing all the handling of the animal and its carcass in one working day, a saving in time of about 50% can be achieved, compared with the conventional system. This means lower inventory costs, and at holiday times and weekends meat does not have to be stored in a meat processing facility in the carcass form, thus avoiding weight loss and loss of storage life of such meat.

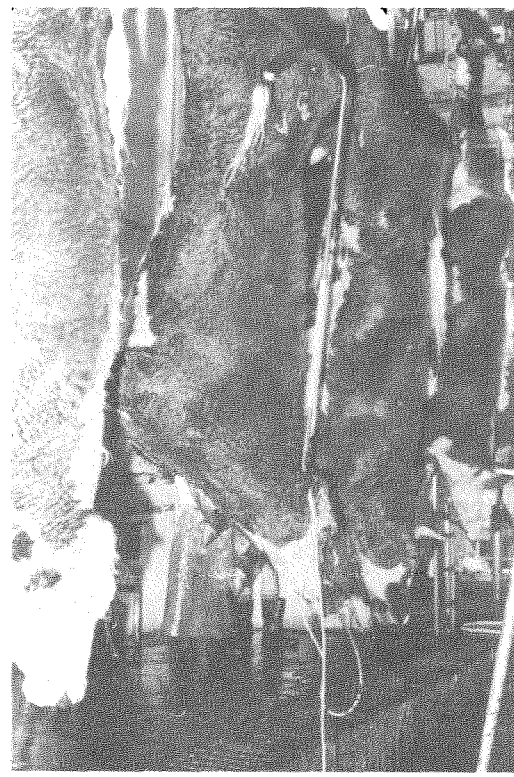

Fig. 2. Extra low voltage stimulation shortly after bleeding

- In conventional meat processing facilities, manpower is normally used to move carcasses in and out of chillers. Hot-boning could save some of these labour costs.
- One of the minor benefits claimed for the technique of hot-boning is that if hot-boned meat is vacuum-packed whilst still hot, less weep (meat juice) is produced in the pack during subsequent storage. In small-scale industrial trials it has been reported that weep is reduced by about 30% thus producing a more attractive pack and bigger yields.

The system does however have some disadvantages. The creation of a large number of warm and moist surfaces by the practice of hot-boning establishes a very large area of meat on which the environment for the growth of both food spoilage and food poisoning bacteria is ideal. Consequently, the safe handling of hot-boned meat is much more difficult than with meat handled conventionally. As a result of work done at the CSIRO Meat Research Laboratory, the behaviour of bacteria on hot-boned meat is now understood more fully. These studies form the basis of the Commonwealth Department of Primary Industry requirements that hot-boned meat be cooled rapidly to a temperature of below 8 °C.

Conventional freezing equipment presently installed in most Australian abattoirs is not capable of reducing the temperature of hot meat in cartons sufficiently quickly to avoid substantial growth of food poisoning bacteria. However, plate freezers, which will enable sufficiently rapid cooling to take place, are available and are being mechanized. Commercial trials have been carried out using CO_2 snow and liquid nitrogen tunnels to accomplish a certain amount of cooling and to allow the existing meatworks refrigeration plant to complete the job.

Finally, there is substantial risk of meat toughening if hot-boning, followed by rapid cooling, is undertaken. But by electrically stimulating the carcass the risk of meat toughening can be minimized.

Bar code technology for the meat industry

All plants spend much time and effort collecting data and it is by analysing such recorded data that an enterprise is able to exercise its control, planning and operating functions effectively.

Most meatworks use a variety of manual methods to record and analyse data on product flow. With manual methods, however, there is the element of human error, and it is often difficult to motivate those who do the simple but important recording job. Keying of data through a computer terminal does minimize error once data have been fed into the memory, although human errors in copying and keying persist. Consequently, if data can be fed into the computer memory at the source, using a sensing device, then the elements of human error can be minimized or eliminated.

Bar code technology can provide satisfactory solutions to the above problems. Bar code scanners are highly accurate in decoding, allow generous tolerances in a number of parameters, and can handle high throughput. Data are fed directly into computer memory, bypassing manual keying and calculating.

In the United States, Australia, the EEC and Japan, most goods sold in supermarkets and retail stores are marked with a type of machine-readable bar code. At the checkout a scanner can be used to decode the bar code and identify the goods and their price. A docket showing full details of the product, price (retrieved automatically from computer memory) and total sum of money to be paid is automatically printed on-line. The accuracy of these machines is claimed to be 99.9% or better. The speed of decoding and hence the speed of passage through the checkout is much faster than with manual methods. In addition, sales information is readily available to management. Inventory is automatically adjusted and a printout of items that require replenishing can be obtained. It can also be tailored to provide accounting and marketing information.

The success of bar coding in supermarket programs will require standardization of codes. In Australia, efforts are being made towards establishing a standard code for the meat industry, thus creating an opportunity for the industry to take advantage of new technology.

The type of bar code used in retailing is generally not suitable for use in production or manufacturing because the code has to be placed very close to the scanner during the decoding process. A larger low-density bar code, however, can be scanned from a distance making it suitable for use on goods carried by a conveying system. The pattern

that is likely to become the standard one is interleaved 2 of 5.

The results of tests by the CSIRO Meat Research Laboratory indicate that bar code scanning is the best method for automatic capture of data from labels attached to meat cartons.

As the name suggests, a bar code consists of a series of dark lines or bars arranged in a ladder-like or a picket fence-like manner. The background must be light in colour to give sufficient optical contrast between bars and spaces.

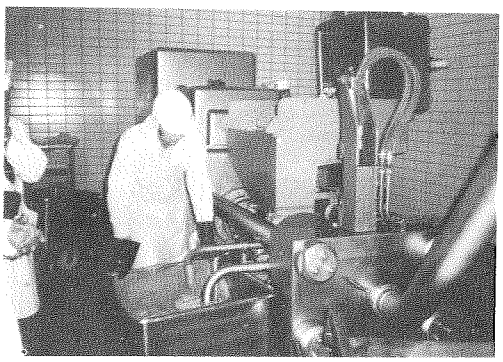

Fig. 3. Mechanically separated meat coming out of the mechanical deboning machine

Operation. — If all cartons produced in a meatworks are labelled with bar codes that indicate the carton contents, then the production record can be monitored automatically using a beam scanner, or semi-automatically by using a hand-held scanner in any suitable location.

The operation of a system using bar code technology is briefly described as follows: In a boning room, the packers affix bar code labels onto cartons before or just after the meat is packed. The packed cartons are then pushed onto a conveying system which takes them to a digital scale. A scanner is situated next to the scale so that the carton concerned is identified before it is weighed. Upon determining the carton weight, the scale activates a printer *via* a micro- or a mini-computer.

There are two methods by which dependent variables such as random weight and date of production can be encoded. The first method records the information encoded as bar code symbols on printed labels, which are then affixed to the cartons. The advantage of such a method is that the information is available to all users, as in the case of product codes. The disadvantages are that the code must be printed on-line and the physical size of the label limits the number of symbols that can be printed on it and consequently, the amount of information that can be stored.

In the second method a unique code (or number) is allocated to each carton and can be used as a reference number to record net weight, production date, shift and any other relevant information. Sequentially numbered (or coded) labels can be preprinted and affixed to cartons before packing, or automatically on the production line. This method does not require on-line printing facilities, and is cheaper than the one previously described. The disadvantage is that it is an in-house system, the unique carton code being meaningful only to the packers.

All the relevant information which has been previously stored can be retrieved by scanning the bar code labels on each carton with a hand-held pen as it is loaded out of a works. Load-out dockets and invoices can be printed automatically, and inventory adjusted.

Bar code technology can provide significant improvements in production recording, report generating, operational planning and control, and various degrees of automation in materials handling.

Yields

Mechanically separated meat

In any butchering process, a certain amount of muscle tissue is left firmly attached to the bones after the commercial cuts are removed. Whether it is red meat, poultry or fish, it has a composition similar to that of the normal cuts and is valuable as a human foodstuff. It is therefore sound economy to recover this meat, if it is economically feasible to do so, before consigning the inedible residues to non-food uses.

Mechanical deboners have been developed which are capable of removing additional tissue from the bones (particularly neck and back bones) after the partial removal of meat

by hand. Among the reasons for their development was the fact that, increasingly, carcasses and quarters are being cut up more completely and deboned at the meatworks or in special boning and processing centres rather than at local distribution centres or retail butcher shops. Demand for meat for further processing, as in the manufacture of sausages and other smallgoods, and in canned meat products, has also been increasing.

An estimated 300 000 tonnes of bones with adhering red meat are rendered to low value products each year in Australia. Probably one-fifth of this could be recovered by mechanical deboning, i.e. about 60 000 tonnes, or equivalent to the annual red meat consumption of about one million Australians.

Recovery of meat from bones by mechanical deboning is a relatively simple process. The bones are forced against the screened or slotted (sieve or compression type) surface of the deboner. The muscle and other edible tissue pass through the openings; the bones and bone particles, except for the very small pieces, do not.

Obviously, the yield of meat from bones will vary, depending on the species of animal and the part of the carcass from which the bones come. The yield of recovered meat and the efficiency of separating the bone depend on the design and operation of the equipment. Mostly, yields will be between 20% and 30% of the total weight of material put into the machine.

The microbial load in the recovered meat depends on the quality of the starting material, and on the measures taken to clean the machine and to control the development of heat during separation.

Mechanically-separated meat (MSM) emerges from the machine as a finely ground paste-like product, a large part of which is muscle protein. Other materials such as collagen, together with varying amounts of fat and bone marrow, are also present.

The protein, fat and moisture content of MSM is determined by the composition of the material being processed. This in turn is influenced by the animal species, the part of the carcass from which the material comes, and by the efficiency of conventional boning techniques used for removing the commercial cuts. The approximate composition of MSM from bones of mature animals, and that of mince meat, is given in Table 1.

Table 1. Approximate composition of MSM and mince meat

Component	MSM	Mince meat
Protein (%)	11–18	14–21
Fat (%)	22–29	17–24
Moisture (%)	55–62	60–67

Some concern has also been expressed about the nutritive value, especially the protein quality and the presence of bone, of products in which MSM is used. Neither concern is well founded. Collagen protein (from the cartilage, gristle and tendon), which is of low nutritional quality, is largely removed during mechanical deboning, leaving only 2% to 4% in the mechanically-separated product. The percentage of collagen and the protein quality of the product are comparable with those of meat deboned by conventional methods.

Most of the deboning machines used in the Australian red meat industry are of the compression type. The bone content of product from these machines is normally less than that of the product from sieve-type machines and the calcium content of the mechanically-separated meat will be little different from meat deboned by hand. The maximum calcium content permitted by the regulations of the US Department of Agriculture is 0.75% and is readily achieved.

Marrow contains protein and fat. On storage, the marrow fat tends to oxidize at a rate greater than the fat of meat. This is one of the limitations of MSM. The amount of marrow constituents in MSM is much less with compression-type machines than with sieve-type machines. The marrow content can be reduced by omitting marrow bones and by accepting lower yields of recovered meat.

Bone marrow is high in haemoglobin, which, in turn, is rich in iron. As the iron intake of Australians is comparatively low, particularly among pregnant women and young children, the presence of iron in MSM products could possibly be considered as a nutritional 'plus'. Mechanically separated meat has two to three times as much iron as do conventional meat cuts.

The recovery of MSM and its use in processed products could prevent the loss of large amounts of expensive and nutritious animal protein which is currently converted into animal feeds, or fertilizer.

Edible blood

During the last few years, shortages and rising prices have stimulated interest in all possible sources of protein for human consumption. Another potentially valuable source is blood from abattoirs. Large quantities are available and the proteins in it are of the highest value nutritionally. Currently, animal blood in Australia is, with few exceptions, recovered as an animal feed material. It is sold either as dried blood, or it is mixed with the meatmeals also produced as a byproduct of the slaughtering operation. Apart from the contribution to world nutrition that recovery of blood as an edible product could make, the upgraded products would have at least a five-fold increase in value. The amount of raw blood recoverable by bleeding livestock varies, but is of the order of 3% of the live weight.

At present, blood equivalent to at least 20 000 tonnes of the dried product containing 10% moisture is available annually at Australian meat-works. On a comparable moisture basis this is approximately equivalent to twice the tonnage of Australia's total annual production of canned meat.

Composition. — It is remarkable that the protein and water composition of meat is very similar to that of raw blood. Lean meat is approximately 75% water, 19% protein and 3% fat. Whole blood has a water content of approximately 80%, protein 18% and fat 0.1%.

Blood comprises a yellowish fluid called plasma in which red and white blood cells are suspended. The oxygen transporting protein (haemoglobin) of red blood cells gives blood its characteristic colour. Plasma is that part of the blood remaining after the removal of the cells from unclotted blood. It accounts for some 60% of the total wet weight of whole blood.

The most abundant protein in plasma is albumin. The next major protein is globulin and the third is fibrinogen, which plays an important part in the blood clotting process.

Collection. — Blood that is to be saved for edible purposes must be collected without contamination. To be acceptable, techniques of collecting blood must ensure that the skin through which the blood is taken is prepared in such a manner that contamination of the blood is avoided. With pigs this is done by applying a gas torch and shaving. With cattle a portion of the hide is grasped by hand and removed by a single stroke of a sterile knife, thus exposing an area of tissue having minimal contamination. A hollow-bladed sticking knife is then inserted which severs the blood vessels and conveys the blood through tubing to a holding tank. It is generally batched either on the basis of animal number or elapsed time. All blood batches must be held until the animals from which the blood has been collected have been passed as fit for human consumption. If a carcass is condemned then the batch of blood is used for processing into animal feed, and the complete line from knife to holding tank must be cleaned and sanitized.

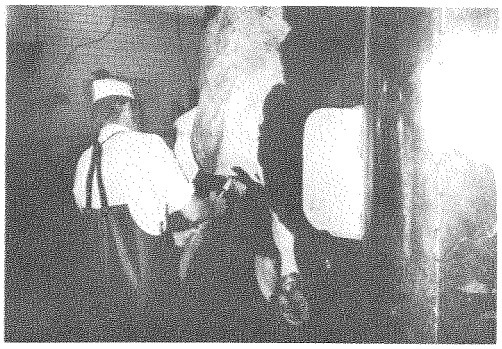

Fig. 4. Inserting hollow handled knife for edible blood collection

Clotting of the blood is prevented by the addition of an anticoagulant, such as a solution of sodium citrate in water, and plasma and blood cells are then separated by centrifugation. The plasma can be concentrated by ultrafiltration and is subsequently preserved by either freezing or low-temperature drying.

The main use of edible grade blood

Table 2. Approximate composition of blood and plasma

Component	Whole blood			Plasma		
	Beef	Pig	Sheep	Beef	Pig	Sheep
Water (%)	80	78	82	91	91	92
Haemoglobin protein (%)	11	14	10	—	—	—
Other protein (%)	7	6	6	7	7	6
Non-protein solids (%)	2	2	2	2	2	2

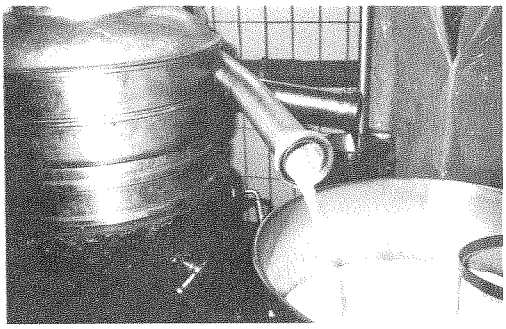

Fig. 5. Plasma being separated from the whole blood

fractions is in the food industry. Plasma is highly valued since it does not impart colour to end products such as smallgoods, hamburgers and pies. Up to 10% of the meat protein can be replaced by plasma protein (allowing for the respective water content in meat and plasma). It is also used in the production of confectionery, pastry, cake and bread, and replaces egg albumen during the preparation of a number of these products. As is the case for mechanically-separated meat, the value of plasma is likely to depend upon the cost of other high quality protein alternatives.

Because of its intense red colour, haemoglobin has a limited use in blood sausage commodities, soups and meat pies. The value of haemoglobin is likely to be dictated by the pet-food and stock-food industry. Pet-food manufacturers are reluctant to use too much as the heat processing during canning results in a very dark product.

Summary

This account has necessarily been somewhat brief and has dealt with only a few examples of the new techniques and technology being used in meat processing. However, not only is there room for the incorporation of new technology within the Australian meat processing industry, but there is technology available now for adoption, and those meat processing operations which survive the 1980s will adopt a great deal of the available new technology and will reap the benefits.

Further reading

The information in this article was drawn from the following:

Chua, H. M., and McPhail, N. G. (1982). Bar code technology — Its use in the Meat Industry, In *Advances in Meat Science & Technology III*, Proc. of Seminar, Brisbane, pp. 11-1 to 11-11, (CSIRO Div. of Food Res: Cannon Hill, Qld).

Field, R. A. (1981). Mechanically deboned red meat, *Adv. Food Res.* 27, 23-107.

Graham, A., and McPhail, N. G. (1974). Blood — Collection and processing for edible purposes, CSIRO Meat Research Report No. 4/74. (CSIRO Div. of Food Res: Cannon Hill, Qld). 29 pp.

Kerr, D. T. (1981). Electrical stimulation of beef carcasses and sides. Industry Guidelines, CSIRO Meat Res. Special Rep. 34 pp. (CSIRO Div. Food Res: Cannon Hill, Qld).

Walker, D. J. (1981). Accelerated processing of beef, *Proc. Meat Quality Control Workshop*, CSIRO Meat Res. Lab. (ed W. F. Spooncer) pp. 95-105. (Hawkesbury Agric. Coll., NSW).

Photosensitive oxygen scavenger films: an alternative to vacuum packaging*

By M. L. Rooney

CSIRO Division of Food Research, North Ryde, N.S.W. 2113.

Introduction

Oxygen-sensitive foods should be stored in packages with initial contents of headspace oxygen below 2% to ensure long shelf life. Low oxygen contents in packages are usually obtained by removal of air using evacuation and/or gas flushing before sealing the package. There have been very few attempts to replace the vacuum/gas-flush procedure with an in-pack deoxygenation system. Kamijo and Rikimaru (1975) used sachets containing hyposulfite, calcium hydroxide and carbon to remove oxygen from pouches having a water-saturated atmosphere. Yoshikawa *et al.* (1977) used iron, carbon and water as a scavenger system, which removed 13 cm^3 of oxygen in 10 hours.

Existing oxygen scavenging techniques present problems due to the nature of the medium in which the reaction with oxygen occurs. Oxygen is removed by reaction either on particulate solids or in aqueous solutions, both of which present containment problems in food packages. Another problem is related to the reactivity of the oxygen molecule in its ground electronic state. Ground state oxygen has triplet multiplicity whereas most other molecules are in the singlet ground state. Thus ground state oxygen is relatively unreactive at room temperature so oxygen removal by conventional chemical means is slow. In contrast, ground state oxygen is reactive enough to cause off-flavour development in some foods over a period of weeks or days. The singlet excited state of oxygen which is obtained by dye sensitization of ground state oxygen using near infrared, visible or ultraviolet radiation, is highly reactive and so its chemical reaction with scavengers is rapid.

The aim of the present study was to investigate factors influencing the efficiency of oxygen scavenging from air headspaces by the singlet oxygen process. The scavenging system utilizes the high reactivity of singlet oxygen and employs a polymer film as the reaction medium.

The new technique involves sealing a small coil of ethyl cellulose film containing a dissolved photosensitizing dye such as tetraphenylporphine (TPP), and an acceptor such as difurfurylidenepentaerythritol (PEF) in the headspace of a transparent package. On illumination of the film with light of the appropriate wavelength, excited dye molecules excite oxygen molecules, which have diffused into the polymer, to the singlet state. These singlet oxygen molecules in turn diffuse to react with acceptor molecules, which are essentially immobile in the matrix, and are thereby consumed. The scavenging process continues as long as the polymer is illuminated, and until all the acceptor or headspace oxygen has reacted.

Photochemical scheme

The photochemical processes involved may be set out as follows:

$$\text{PHOTON} + \text{DYE} \rightarrow \text{DYE}^* \quad (1)$$

$$\text{DYE}^* + \text{OXYGEN} \rightarrow \text{DYE} + \text{OXYGEN}^* \quad (2)$$

$$\text{OXYGEN}^* + \text{ACCEPTOR} \rightarrow \text{ACCEPTOR OXIDE} \quad (3)$$

$$\text{OXYGEN}^* \rightarrow \text{OXYGEN} \quad (4)$$

where * indicates the dye or oxygen in an excited state. While light excitation of the dye initially produces the excited singlet state (reaction 1), conversion to the triplet excited state is very fast and it is principally this state of the dye which excites the ground state oxygen to the singlet state (reaction 2). Any reaction with an acceptor (reaction 3) always

*A paper presented at the Food Study Group Symposium of the Defence Science & Technology Organisation of the Department of Defence, held at CSIRO Division of Food Research, North Ryde, N.S.W. during May 1982.

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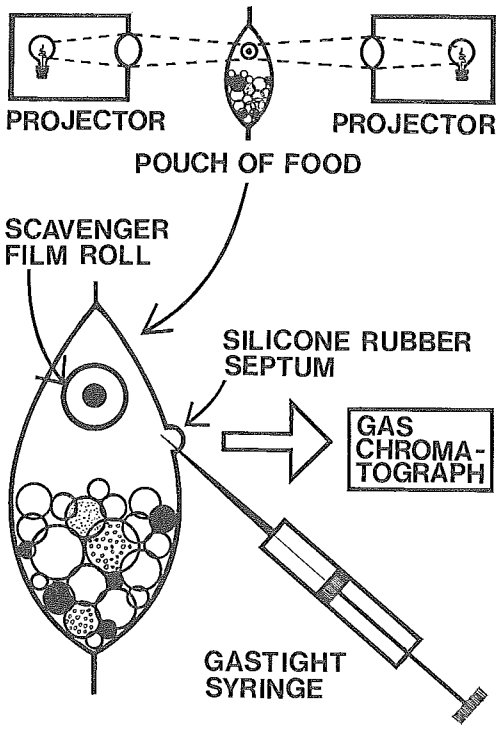


Fig. Headspace oxygen removal by photochemical scavenging monitored by gas chromatography.

occurs in competition with the physical quenching of singlet oxygen to the triplet ground state (reaction 4).

Test procedures

Air-filled pouches

A strip of scavenger film 4 cm wide and of chosen length and thickness was rolled loosely into a coil having a diameter of approximately 4 cm. Silica particles (0.5 mm diameter) in the film surface were used as an antiblocking agent to hold the layers of film apart. The coil was placed in a pouch, 11 x 6 cm, of oriented polypropylene coated with polyvinylidine chloride as described previously (Rooney *et al.* 1981). After the pouch was heat-sealed, the air was withdrawn by means of a two-way syringe (Shorter 1982) through a silicone rubber septum (Silastic, Dow Corning) extruded onto the pouch's outer surface. An appropriate volume of air was then injected into the pouch without the need for a second puncture.

The pouch was then hung vertically between two 500-Watt photographic slide projectors at a distance of 35 cm from each lamp. The average illumination at each surface of the pouch was 2×10^5 lux. To measure the effect of light intensity the average illumination was increased to 7×10^5 lux. This was obtained by reducing the distance between each projector lamp and the pouch to 12.5 cm. Samples (0.2 cm^3) of headspace gas were withdrawn using a gas-tight syringe (Precision Sampling Corp.) for analysis by gas chromatography (Rooney *et al.* 1981). Triplicate pouches were used for each test.

Pouches containing food

Cashew nuts (22.5 g) or potato crisps (4 g) were placed in pouches and a roll of scavenger film was inserted between the food and the top of each pouch. The scavenger film, 105 cm long, 4 cm wide and 12 μm thick, contained PEF and TPP at concentrations of 0.6M and 10^{-3}M respectively. The pouches were sealed and the headspace volumes were determined from the decrease in total pouch volumes after scavenging of the oxygen. Duplicate pouches were then prepared and the air volumes were adjusted to these levels by means of a gastight syringe.

The scavenger film was illuminated by aiming the lamp at the top area of the pouch to avoid any unnecessary exposure of the food to strong light. The food may also be shielded from light by use of a screen, by adjusting the height of the fill, or by filtering out any wavelengths of light which might be deleterious.

Results and discussion

Air-filled pouches

The rate of a photosensitized singlet oxygen reaction in a polymer film can be limited by either diffusion or light intensity (Rooney 1982; Rooney *et al.* 1981). Experiments were conducted to determine the importance of these two variables in the present system.

Film area

Rolls of scavenger film, containing PEF (0.4M) and TPP (10^{-3}M) were formed from strips of different length and thickness so that the volume of film and the quantity of both

compounds in each was constant. Thus the same amount of light should be absorbed by each treatment provided light scattering is similar.

Table 1. Headspace oxygen (%) at various times as a function of film area and thickness

Film	Area	Thickness	Time (min)				
	(cm^2)	(μm)	0	2	5	10	15
A	1136	7.5	21	14.4	5.2	0.4	0.4
B	848	10	21	14.6	6.2	0.6	0.3
C	680	13	21	16.8	8.2	2.4	0.6
D	376	23	21	16.2	10.1	4.7	2.6
E	248	38	21	15.8	12.7	8.0	6.3

The results (Table 1) show that the scavenging rates for the first two minutes were similar but in thick films (C–E) they decreased as the reaction proceeded, indicating that the rate was limited by the rate of oxygen diffusion from the film surface to dye molecules surrounded by unreacted PEF molecules. Thus with decreasing film area, the reaction is not limited by diffusion initially but will be when the PEF near the film surfaces is consumed. Replacement of ethyl cellulose with more permeable polymers such as silicone rubbers should give faster rates of scavenging.

Intensity of illumination

Rolls of scavenger film, 140 cm long, 7.5 μm thick, and containing PEF (0.4M) and TPP (10^{-3}M), were sealed in pouches containing air (30 cm^3) and illuminated at two light intensities. The data in Table 2 show that the higher light intensity gave faster scavenging indicating that the reaction rate is limited by the availability of excited dye molecules to excite the oxygen.

Table 2. Headspace oxygen (%) as a function of time at two light intensities

Intensity	Time (min)			
(lux x 10^5)	0	5	10	15
2	21	14.4	5.1	0.4
7	21	9.7	2.1	0.4

Pouches containing foods

Cashew nuts and potato crisps were chosen as examples of oxygen-sensitive foods which when packaged have small (26 cm^3) and large (55 cm^3) headspaces, respectively. The scavenger film contained enough PEF to react with 70 cm^3 of air in each case. The packs of crisps required around 5 min more illumination to reach the 2% oxygen level (Table 3). This difference was probably due to the larger volume of oxygen in the packs of crisps.

Table 3. Headspace oxygen (%) at various times in pouches containing foods

Food	Time (min)				
	0	5	10	20	30
Cashew nuts	21	9.0	3.5	0.8	0.3
Potato crisps	21	13.5	6.0	1.8	0.5

Conclusions

The oxygen scavenging rate depends initially on the light intensity and subsequently on the rate of diffusion of oxygen into the film. Both factors may be varied to maximize the rate of scavenging.

The photo-sensitizing dye, the acceptor or the reaction product may migrate into the food in the present system so polymers with dyes and acceptors as part of the polymer chain are being evaluated.

References

Kamijo, M., and Rikimaru, M. (1975). Evaluation of sodium hypo-sulphite-based deoxygenation agents. (in Japanese) *Yokohama-shi Eisei Kenkyusho Nempo.* **15**, 90. [*Chem. Abstr.* **88**, 168561z (1978)].

Rooney, M. L. (1982). Oxygen scavenging from air in package headspaces by singlet oxygen reactions in polymer media. *J. Food Sci.* **47**, 291.

Rooney, M. L., Holland, R. V., and Shorter, A. J. (1981). Photochemical removal of headspace oxygen by a singlet oxygen reaction. *J. Sci. Food Agric.* **32**, 265.

Shorter, A. J. (1982). Evaluation of rapid methods for scavenging. Headspace oxygen in flexible pouches. *Lebensm. Wiss. + Technol.* **15**, 380.

Yoshikawa, Y., Ameniya, A., Komatsu, T., Inoue, Y., and Yuyama, M. (1977). Oxygen Absorbers. Japan Kokai. 77 104 486: 4.

Whey utilization*

By J. G. Zadow

CSIRO Division of Food Research, Highett, Vic. 3190.

Introduction

A byproduct may be considered to be a material which is produced incidentally as a part of the manufacture of a commercially profitable product. Within the dairy industry, only two materials fit this definition of 'byproduct': whey, and the permeate from ultrafiltration of milk. Some years ago, it was common to consider skim milk as a byproduct, but in the current state of the industry, it is clear that this should now be classified as an end-product in its own right. The same now applies to buttermilk.

Production of whey in Australia is 1 100 000 tonnes per annum from cheese production, and 200 000 tonnes per annum from casein production, a total of about 84 500 tonnes of solids per annum. The amount of permeate from ultrafiltration of milk is quite small at present but is likely to increase as a result of applications of ultrafiltration to the manufacture of cheese and products like 'cheese base'. For the purposes of this review, however, this permeate can be discussed together with whey. The importance of whey utilization is clearly shown by the fact that, in the past eight years, more than 300 review articles have been published.

Strobel (1972) pointed out that there was a paucity of statistics on whey production and utilization. This is still the case for Australia, and for much of the world. Clark (1979) of the Whey Products Institute has given detailed information concerning production and usage of whey in the USA and some information has been published concerning production in the USSR (Danchenkov *et al.* 1979; Preller *et al.* 1978), but there is little detailed information available for other countries.

Methods of whey utilization used by the Australian industry include soil disposal, sewage disposal, animal disposal and conversion to products such as spray-dried whey and whey protein concentrates, but statistics are difficult to obtain. Availability of detailed statistics for whey disposal on an industry-wide basis is highly desirable, and would allow for improved long-term planning of research programs. Within Australia, much whey is utilized as either spray- or roller-dried powder, for use in human and animal foods. There is a dearth of detailed information in the literature on the extent of use of whey in such applications, indicating in all probability that much of the end-use information developed over the years is in the hands of proprietary companies. Similarly, the information on disposal by soil application is also limited with the major contribution being a review of the application of whey on properties of soils and crops by Peterson *et al.* (1979). Ely (1978) has also reported on the use of whey in silage production.

There is little detailed information on economic aspects of whey utilization. However, the contribution by Gillies (1974), although somewhat dated, is useful. Bertrand (1976) discusses whey concentration and protein separation costs and profit margins. The implications of whey utilization on energy savings in the industry have been described by Clarke (1979).

Recent trends in whey utilization have been towards the development and application of the unit processes which have become available in the last decade. In particular, the development of reliable and economic techniques for membrane

*Based on a paper presented at the Second Australian Dairy Technology Review Conference, Glenormiston, Victoria, September, 1982. The paper was intended as an exhaustive coverage of whey utilization. As such, the bibliography was very extensive, but due to limited space, only some references are cited in this publication. Copies of the full bibliography may be obtained by contacting the author.

processing of whey and milk has had, and continues to have, a revolutionary effect on the industry. The number of unit processes available for whey processing is already substantial, and is growing. However, the processes which appear to be commercially viable (excluding drying and evaporative concentration) include ultrafiltration, reverse osmosis, demineralization by ion exchange or electrodialysis, lactose hydrolysis by enzymic or heat/acid processing, lactose crystallization, fermentation (both aerobic and anaerobic), and chemical production. Introducing further complexity into the problems faced by industry manufacturers in process selection decisions is the fact that the most generally applicable method for whey treatment, ultrafiltration, produces two materials (whey protein concentrate and permeate), which in turn may need to be treated by other unit processes. Table 1 shows some of the unit processes which may be applied to whey and whey based products, and Tables 2, 3 and 4 show the end products obtained by application of some of these processes to whey, whey protein concentrate and permeate. A useful review of reverse osmosis and ultrafiltration has been published by Marshall (1982), and aspects of physico-chemical separation processes have been discussed by Muller (1981) in this Journal.

General

In 1979, a whey research workshop was held in Palmerston North, New Zealand, which was attended by 39 research workers representing six countries. The workshop covered all areas of whey utilization, including unit processes, analytical procedures, functionality, energy aspects and product end-uses. The proceedings of the workshop were published in a special issue of the *New Zealand Journal of Dairy Science and Technology* (Marshall 1979*a*), and is a particularly useful reference work in this field. More recently, an issue of *Technique Laitiere* has been devoted solely to all aspects of whey utilization, and this too is a very useful reference work (du Boisbaudry 1981). The emphasis in this latter series of articles again covers the whole gamut of whey utilization from economic aspects and unit processes, to nutritional and functional properties. The application of the Rhone Poulenc 'Spherosil' process to whey protein recovery is also discussed. Other useful review articles covering the full range of whey processing and end-use application have been prepared by Mann (1975, 1977*c*), McDonough (1977), Jelen (1979), Kosikowski (1979*b*) and Morr (1976). Kosikowski (1978), in a detailed report to the International Dairy Congress, followed a discussion of means of whey treatment with a discussion on the potential of whey products in the food industry. Evans (1980) has made a useful contribution to the literature by discussing the less-well-known areas of research in whey technology. These include production of lactitol, use of whey as a powder binder in the steel industry, and use of whey as a source of lactoperoxidase.

Unit processes

Reverse osmosis and ultrafiltration

There is no doubt that without the development of these two processes, the dairy industry worldwide would be facing much greater problems in whey disposal. There has been continuing development and improvement in membrane composition to increase flux, increase membrane life, and reduce costs, and also in engineering design (from tubular to plate and frame, to spiral wrap). These ongoing developments have made the application of reverse osmosis and ultrafiltration much more attractive commercially. Although ultrafiltration has received much greater research and development than reverse osmosis in recent years, the latter is now likely to come into its own for processing of whey and the permeate from ultrafiltration as a means of preliminary concentration before further processing or evaporation and drying.

In terms of energy efficiency, reverse osmosis is now approaching the theoretically possible limits (Marshall, S. M., pers. comm.), but it is probable that some gains in terms of production per kWh remain to be made in ultrafiltration. A number of useful reviews of the application of membrane processing to the dairy industry have been published recently. These include those of Matthews (1979), Glover *et al.* (1978), Itoh (1979), Hallstrom and Eriksson (1977), Murphy (1977), Becka (1976), Delaney and Donnelly (1977), and Ito and Kotake (1978). Of particular interest to the industry and its regulatory bodies are the sanitary aspects of membrane processing. Beaton (1979)

Table 1. Processes for whey treatment

Evaporation to liquid concentrate
Evaporation to semi-solid concentrate
Roller drying
Spray drying
Ion exchange demineralization
Electrodialysis demineralization
Free enzyme lactose hydrolysis
Enzyme reactor lactose hydrolysis
Bound enzyme lactose hydrolysis
High temperature acid lactose hydrolysis
Fermentation — aerobic
Fermentation — anaerobic
Reverse osmosis
Ultrafiltration
Protein complex formation by CMC, polyacrylic acid, iron, tannin, meta phosphate or silica resins
Protein separation by Sephadex gel filtration, ultracentrifugation, heat
Lactose crystallization
Chemical modifications to lactose — lactitol, lactulose
Binder for powders in steel industry
Source of lactoperoxidase

discusses the problems of hygienic design and operation of membrane systems, particularly from the point of view of cleanability and sanitation.

Muller and Harper (1979) have reviewed the effects of pretreatment of whey on membrane processing characteristics. Changes in the chemical and physical characteristics of various types of whey have been shown to have a marked influence on the operating characteristics of ultrafiltration and reverse osmosis plants. Whey treatments which have improved performance during ultrafiltration include clarification, centrifugation (sometimes preceded by calcium addition), heating under conditions determined by type of whey and pH, demineralization, pH control and preconcentration. With reverse osmosis, only demineralization and pH adjustment have been reported to be effective; an understanding of how the changes in the whey affect membrane performance is far from complete.

Recently, a new type of membrane system has been reported (Maubois *et al.* 1981). These membranes are formed from inorganic zirconium oxide supported by a graphite base. Unlike the best ultrafiltration membranes, based on a polysulfone material limited to a maximum operating temperature of 75 °C in the range of pH 2 to 12, the zirconium membranes are resistant to temperatures up to 400 °C over the full pH scale. Such membranes offer clear advantages in terms of sanitation, although little information is currently available concerning flux rates and performance of these systems.

Marshall (pers. comm.) has studied an inexpensive ultrafiltration system manufactured by the Australian Atomic Energy Commission. These inexpensive units were manufactured from domestic polyvinylchloride plumbing materials and pipe, and used locally prepared cellulose acetate membranes. The membrane modules are disposable, and the design requires no stainless steel.

Demineralization

Only two systems are commercially available for demineralization: ion exchange and electrodialysis. Demineralization may often improve the functionality of whey products, and it is often essential if the whey-based product is to be incorporated into infant foods. Electrodialysis and ion exchange are quite different approaches to the same problem and yield products of somewhat different composition. Ion exchange is relatively non-selective, and removes both mono- and poly-valent ions. Electrodialysis separation is more dependent on ionic mobility hence mono-valent ions are preferentially removed. In practice, about 90% demineralization is the upper limit with electrodialysis. The economic aspects of the two processes are also different. The lower capital cost of ion exchange gives it an advantage in small systems, particularly where high degress of demineralization are required. Electrodialysis would be preferred for plants with high utilization and low levels of demineralization, coupled with low electricity costs. Both systems produce substantial quantities of effluent, equal in volume to about double the quantity of whey treated. The relative economics of the processes have been studied by Marshall (1979*b*), and a useful discussion on technical aspects of design and operation of electrodialysis systems, together with some economic data has been published by Kruger (1977). A new process, involving exchange with resins in the ammonium and bicarbonate forms, has been described by Jonsson and Olsson (1981).

The production of demineralized whey powder in Italy, using an ion exchange system, is described by Vecchia (1979). The product is used in biscuits and other baked goods, ice creams, dietetic materials and chocolate-based products.

Recently Hayes (pers. comm.) has reported a novel technique for partial demineralization of whey ultrafiltration permeate. This method involves addition of calcium to the permeate to adjust the Ca/P ratio to that of insoluble calcium apatite. The resultant precipitate can be removed by mild centrifugation, with an effective reduction of more than 60% in the calcium content of the permeate, and a reduction of more than 50% in the phosphorus content. This method is simple and inexpensive offering advantages where only partial demineralization is required, or as a preliminary treatment before full demineralization by ion exchange. This process could also be of interest where lactose hydrolysis by enzymatic treatment requires preliminary partial demineralization. The recovered calcium apatite may have pharmaceutical applications.

Table 2. Processes and products from whey

Lactose hydrolysis	Demineralization	Concentration	Spray drying	Product
✓	✓	✓		Fluid concentrates
✓	✓	✓		Semisolid concentrates
✓		✓	✓	Whey powder
✓	✓	✓	✓	Demineralized whey powder
✓		✓	✓	Lactose hydrolysed whey powder
✓		✓	✓	Lactose hydrolysed demineralized whey powder

Lactose hydrolysis

Two major methods may be used for lactose hydrolysis of whey-based products: the enzyme hydrolysis approach, and, for permeates, the acid/heat method. The interest of the industry appears to be mainly in the field of enzymic hydrolysis, particularly in view of the continually reducing cost of enzyme systems, coupled with the development of reactor techniques for enzyme re-use and of systems using immobilized enzymes. Until recently, Corning Biosystems International made the only commercially available immobilized lactase, using glass beads as support. In the past twelve months however, at least two other immobilized lactase systems have become available, from Novo Industri A/S, Denmark (for permeate only) and Sumitomo Chemical Co. Ltd. There is little doubt that competition will lead to this approach being the preferred technique for lactose hydrolysis, even for small-scale operations.

The acid/heat system for lactose hydrolysis is the most economical method. However, its application is limited to permeate, and decolorization of the product is necessary after processing. It does, however, produce a partially or wholly demineralized product if the appropriate method is used. The cost of demineralization is in addition to the cost of hydrolysis. Heterogeneous acid-catalysed hydrolysis of lactose with cation exchange resins is discussed by MacBean *et al.* (1979).

The use of lactase in the dairy industry has been reviewed by Bartoli (1978) and Bouvy (1975). Single-use enzyme systems are comparatively expensive, and may operate at undesirable temperatures. Although their cost disadvantage may be overcome to some extent by the use of ultrafiltration to recover reactants, these systems may be complex and expensive.

The use of immobilized lactase on milk and whey is discussed by Finocchiaro *et al.* (1980). Baret (1978) has presented a useful article on studies on the Corning immobilized system. The flow sheet, operating characteristics and performance of a 350 litres/hour system, operating at 80% hydrolysis, are described. Bouvy (1975) has reviewed the basic physical and chemical effects of lactose hydrolysis, together with details of the *Saccharomyces lactis* lactase, and its activity in whey. Mustranta *et al.* (1979) discuss the nutritional and technological advantages of hydrolysing lactose, and the types of lactase available. Production, properties and immobilization of lactases, particularly *Aspergillus niger* lactase, are discussed. MacBean (1979) has presented results comparing hydrolysis by lactase immobilized on glass beads with results

obtained by an acid/heat technique.

Hayes (pers. comm.) has reported that when concentrated whey or permeate was subjected to enzymic hydrolysis of lactase at 55°–58°C, coagulation was observed. The clotting of the whey concentrates was believed to be due to the action of residual rennet, whereas calcium phosphate complexes were believed to be involved in the mechanism of permeate coagulation.

There is little evidence in the literature of flavour difficulties being experienced due to enzymic hydrolysis. Experience at the Dairy Research Laboratory, CSIRO, indicates that this may be a problem with some enzymes (both free and immobilized) and some wheys. It is clear that this problem will need to be overcome if this system is to be viable.

Lactose crystallization

Although techniques for lactose crystallization are well described in the literature, it is believed that world production of lactose is not large. Demand for lactose is highly inelastic, there being little demand for increased production. MacBean (1979) has reported on the cost of production of USP grade lactose in Australia and its end uses. Efforts in Australia have been aimed at developing a process based on a single-stage continuous crystallizer with control over the rate of nucleation. For conventional lactose crystallization processes, capital costs are high and may prohibit the establishment of new plants. The successful development of a continuous crystallization system would offer great advantages to the industry. Studies on this system have been reported by Muller (1979).

Fermentation processes

The technology for production of alcohol and single-cell protein from whey has been available for many years and little new information has been added in recent times. It is considered unlikely that fermentation of whey to either product would be economically viable in Australia. Various aspects of the utilization of whey as single-cell protein products/yeast biomass have been discussed by Moebus (1976), Moebus and Lembke (1975) and Mergl and Uher (1975).

The preparation of fuel alcohol from whey is discussed by Lyons and Cunningham (1980). Cheese whey is claimed to have a very low net feed-stock cost per gallon of ethanol

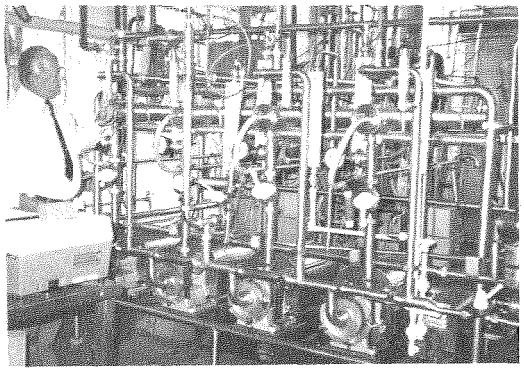


Fig. 1. Pilot Scale UF plant

produced, and potential production in the USA is 90 million gallons/year. Three processes are described; the Milbrew system based on *Kluyveromyces fragilis* (primarily designed for single-cell protein production), the continuous Carbery process in commercial operation in Ireland and New Zealand, and the Danish process from whey permeate. Lang (1980) has also reviewed the use of whey as an energy source, with particular emphasis on anaerobic fermentation to produce biogas.

Other processes

Chemical modification

There are a number of options available for chemical modification of whey and whey components. These include production of lactitol, lactulose, lactobionic acid, lactosyl urea and lactic acid. Some of these applications have been reviewed by Zadow (1979).

Protein separation techniques

Gel filtration, co-precipitation with CMC or metaphosphate, iron complexation. — A number of methods have been described for protein separation from whey using these techniques, but for various reasons, they do not appear to be commercially viable and will probably remain of only academic interest. The status of these techniques has been discussed by Marshall (1979*b*).

Spherosil. — Recently, Rhone Poulenc Chemie Fine have announced the development of a novel system for whey protein recovery, based on the passage of whey through a column containing a resin ('Spherosil') which specifically adsorbs

Table 3. Processes and products from whey protein concentrates

Lactose hydrolysis	Demineralization	Concentration	Spray drying	Product
		✓		Fluid WPC
		✓		Semisolid WPC
		✓	✓	WPC
	✓	✓	✓	Demineralized WPC
✓		✓	✓	Lactose hydrolysed WPC
✓		✓	✓	Lactose hydrolysed demineralized WPC

protein. The protein is recovered by washing the column with a solution of slightly different pH to the whey. This approach offers substantial advantages. These include the production of a pure protein product of extremely high functionality, a process with minimal operational costs, and production of a protein-free waste, similar in composition to ultrafiltration permeate. Examination of the products of this system at the Dairy Research Laboratory, CSIRO, has confirmed the extremely high functional properties of this product, with its characteristics often being superior to those of egg white. The product is vastly superior to 80% whey protein concentrate in functionality, reflecting perhaps not only the higher protein content of the Spherosil product, but perhaps also the effect of energy input during ultrafiltration on functionality of whey protein concentrate. Currently, most of the information on this system in the literature originates from Rhone Poulenc. It is certain, however, that this process will attract the attention of dairy research establishments throughout the world. Mirabel (1981) has reported on the application of Spherosil to whey protein recovery, and includes some estimates of cost of production compared to ultrafiltration processes.

Heat denaturation. — Technology for production of lactalbumin by heat denaturation is well known, and is discussed by Robinson *et al.* (1976), and by Greig (1979) with emphasis on processing methods, and their effect on end-product properties and nutritional characteristics. Pearce (pers. comm.) has recently described a novel method for whey protein separation and precipitation based on heat treatment of whey at specific pH and closely controlled temperatures. Significant fractionation of whey proteins is possible by this method.

Drying

Currently, much of the permeate produced in both the USA and Europe is finding a ready market after spray drying. Much of this material is used in bottled goods and infant foods. This simple option for permeate utilization offers many advantages and should be explored by the Australian industry before it becomes too heavily involved in some of the more complex manufacturing processes outlined above.

Composition and analysis of whey-based products

Problems and methods used for analysis of whey-based products are reported by Harper (1979). Delaney (1976) has given details on composition of whey protein concentrates manufactured by various techniques. The effect of ultrafiltration, reverse osmosis and demineralization of whey on nutritive and chemical composition have been detailed by Thapon (1977). Similar information has been reported by Fevrier (1979) and Watanabe (1980).

A technique for determination of extent of lactose hydrolysis based on freezing point depression has been described by Zarb and Hourigan (1979). Hayes (pers. comm.) has also developed methods for this purpose based on the use of a polarimeter or a blood glucose unit. Hayes (pers. comm.) has reported on the determination of degree of lactose hydrolysis by freezing point depression. The method requires a knowledge of the lactose content of the unhydrolysed sample, and of the difference in freezing point between the hydrolysed and unhydrolysed samples. The method has been applied successfully to the determination of extent of hydrolysis of ultrafiltrate, permeate and milks.

Functionality

The functional properties of whey protein concentrate are their most important characteristics in relation to their end-uses and to the economics of their manufacturing

and marketing. Although there has been much work world-wide to attempt to relate compositional characteristics of the concentrates to functional properties, this has in the main been unsuccessful, except in model systems. However, as more detailed information about the influence of molecular structure and interaction becomes available, a greater understanding of the influence of these factors on functionality in formulated foodstuffs should be achieved.

De Wit (1981) has examined the structure and functional behaviour of whey proteins as affected by heat, pH and calcium, and stressed the role of the thermal behaviour of β-lactoglobulin. The solubility characteristics of whey proteins have been reviewed by Suter and Puhan (1977), whilst Smith (1976), Kamiya and Kaminogawa (1980), Craig (1979) and Morr (1979) have discussed the functionality of whey-based products in wider terms. Richert (1979) has recently published an article outlining the factors controlling the behaviour of whey protein foams.

Britnell (pers. comm.) has examined the water absorption capacity of whey protein powders, prepared by freeze drying or spray drying. The freeze-dried samples had significantly higher water absorption capacity than the spray-dried powder. Water absorption capacity for the freeze-dried powders ranged from 778 to 984 g water per 100 g protein, while that of the spray-dried powder ranged from 627 to 752 g of water per 100 g protein.

The Whey Research Workshop in 1979 recognized the importance of studies on functionality. As a result a collaborative effort is being maintained involving the Dairy Research Laboratory, CSIRO, the New Zealand Dairy Research Institute, and in the USA, Clemson University and Ohio State University.

End-product utilization

Despite the number of alternative outlets for whey products for the foreseeable future, the major outlet for whey and whey-based products in Australia will be as foods for animal or human consumption. The general application of whey powders as foodstuffs has been discussed by Vyas *et al.* (1980), Tsugo and Kosikowski (1979), Kosikowski (1979*a*), Dunkley (1977) and Holmes and Shahani (1979). A common theme of most of these articles is the difficulty of disposal of lactose.

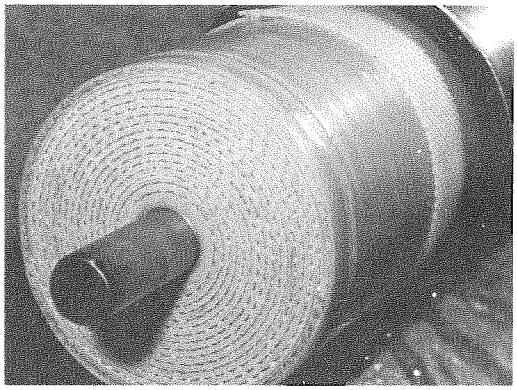


Fig. 2. Spiral wound UF membrane

Animal feed

Processes for manufacture of animal food products from skim milk, whey and permeate have been outlined by Hansen (1978), covering a wide range of manufacturing processes and final products. An evaluation of whey utlilization in animal feeding has been made by Schingoethe (1976*a*), in which he reports that ruminants can consume up to 30% of their dry matter intake as liquid whey without impaired performance, whilst pigs may experience diarrhoea if more than 20% of their intake is liquid whey. Reviews of feeding of whey-based products to animals have also been written by Bredeveien *et al.* (1976), Nielsen (1976*a*, *b*), Jensen (1978), Mann (1977*b*), and Juengst (1979). More specific applications of whey feeding to animals have been reported by Thivend (1977); Fisher and Lister (1974) (feeding to ruminants); Schingoethe (1976*b*) (non-ruminants); Andersen (1978) (cattle); and Plonka and Szwej (1977) (fattening pigs). A detailed study on the use of whey protein concentrate in calf feeding has been reported by Stewart *et al.* (1974).

Human food

The main interest in whey utilization lies in its future use as an ingredient in human foodstuffs. The list of existing applications for whey products is already long, but there is considerable potential for expansion. Mann (1977*c*) and Mathur and Shahani (1979) have reviewed the use of whey constituents in human foods. Ulrich (1976) has examined the modifications necessary to make whey products suitable for use as ingredients in infant formulations.

Flavour and nutritional aspects

As mentioned previously, there is little evidence in the literature of flavour problems with whey products, in spite of the difficulties experienced with some lactose hydrolysis systems at the Dairy Research Laboratory, CSIRO.

Primatesta (1976) has discussed the effect of ultrafiltration and reverse osmosis on the nutritional value of whey proteins, and Wagner (1980) has reported on the nutritive importance of whey. Much literature on lactose intolerance is available (e.g. Holsinger (1978)) in which applications of lactose-modified milk and whey have been considered. Forsum (1975) has reviewed the role of whey proteins from the nutritional and biochemical points of view.

The effects of whey-based drinks on osmolarity have been studied by Wagner *et al.* (1975), and the presence of nitrates and nitrites in milk and whey detailed by Bertelsen (1978).

Specific applications

Ice cream and desserts. — There is considerable potential for the application of whey products in this field, either as a skim milk powder replacer, or, in the case or hydrolysed whey-based products, as partial sucrose replacers. Within Australia, there already is considerable interest in this application by a number of ice cream manufacturers. The application of whey products in ice cream has been described by Dalum (1976), Mann (1978), van Gennip (1980), Tobias and Muck (1981) and Bianchi-Salvadori (1978).

The use of whey products in desserts has been described by Nielsen (1974), and the use of whey in jellies by Sienkiewicz *et al.* (1976). For ice cream and desserts, the sweetness of the mixture is of the utmost importance, and many of the publications recommend the use of hydrolysed whey products in these materials. Lang and Lang (1977), Bartoli (1978) and Short (1978) have described the applicability of lactose-hydrolysed products in such systems.

Confectionery. — Both normal and lactose-hydrolysed whey products have considerable potential in this field. In particular, hydrolysed whey protein concentrate forms products with a pleasing caramel colour and aroma on heating in aqueous suspension, a factor which could prove attractive to the confectionery industry. Spurgeon (1976) and Riedel and Hansen (1979) have reviewed the application of whey products in the confectionery industry. Riedel and Hansen see particular application for the replacement of condensed milk with condensed whey in confectionery.

Baked goods. — The replacement of skim milk powder in bread by a whey protein concentrate analogue is well known to result in reduced loaf volume. Recent work at the Dairy Research Laboratory, CSIRO, has indicated that this problem may be overcome by application of correct manufacturing conditions during the preparation of the whey protein concentrate. Trials to evaluate the performance of such treated concentrates are in hand. Reviews of the role of whey products in the baking industry have been prepared by Mann (1977*d*, 1980*a*), Guy (1978), de la Gueriviere (1979), Preller and Rohrig (1978, 1979) and Grandvoinnet (1977).

Meat. — There is comparatively little data available on the use of whey products in meat, an area which would appear to have much potential. This may reflect a low level of communication between these two arms of the food industry. Certainly whey protein concentrates with their high water absorption and high gelation characteristics should be of

Table 4. Processes and products from UF permeate

Fermentation	Lactose hydrolysis	Deminera-lization	Lactose crystallization	Chemical modifications	Concen-tration	Spray drying	Product
	✓	✓					Glucose-galactose syrups
		✓	✓				Lactose
		✓		✓			Lactitol, lactulose lactosyl urea
✓							Alcohol, methane
					✓	✓	Stock foods
					✓	✓	Spray dried permeate

interest to the meat industry. Applications of whey products in this field have been considered by Pinel (1981) and Durand and Frouin (1977).

Cultured milk products. — Again, the most likely application for whey-based products in cultured milk products is as a skim milk powder replacer. The practicality of this is currently being examined in a number of products by the Gilbert Chandler Institute of Dairy Technology, with quite a degree of success. Nielsen (1976*b*) has reviewed the use of whey solids in cultured milk products, and Cerna (1979) has outlined studies on the production of yoghurt of increased protein content by adding whey protein concentrate.

Egg replacers. — In purely economic terms, this is the most desirable application of whey proteins. Egg proteins command an extremely high price in the market place, and therefore whole or partial replacement of these materials by whey protein concentrate is a most attractive option to the end user. Niroumand (1978) and Paquet (1981) reviewed the possible applications of whey products as egg white replacers in food systems.

Beverages. — The success of a number of industries in the development of markets for products containing alcohol produced from whey in the USA and Ireland has elicited much interest. Articles discussing the production of alcoholic beverages from whey have been published by Lang and Lang (1979), Mann (1980*b*), Monzon (1977) and Sienkiewicz and Riedel (1975).

For use in non-alcoholic still or carbonated beverages, Hayes (pers. comm.) has indicated that partial demineralization and lactose hydrolysis is necessary if sedimentation is to be avoided in the product. Review articles describing the application of whey products in beverages have been prepared by Mann (1981, 1977*a*), Lang and Lang (1976), Sienkiewicz and Riedel (1978), and Kosikowski (1981).

Conclusions

Major trends in by-product utilization are likely to be:

- greater use of membrane processing for both fractionation and concentration, leading to large quantities of permeate from milk and whey for disposal
- extensive use of lactose hydrolysis by immobilized systems
- development of systems for recovery of highly functional protein fractions from milk by-products by means akin to the Spherosil process
- closer liaison between the food industry and the dairy industry to devise new and novel outlets for by-product derivatives.

References

Baret, J. L. (1978). *Ind. Aliment. Agric.* **95**, 957-62.

Beaton, N. C. (1979). *J. Food Prot.* **42**, 584-90.

Boisbaudry, P. du (1981). *Tech. Lait.* **952**, 5.

Forsum, E. (1975). *Naringsforsk.* **19**, 127-40.

Gillies, M. T. (1974). *Food Technol. Rev.* **19**, 211 pp.

Harper, W. J. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 156-71; 180-4.

Holmes, D. G., and Shahani, K. M. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 208-13.

Holsinger, V. H. (1978). *Food Technol.* **32**, (3) 35-6, 38, 40.

Kosikowski, F. V. (1978). *Conf. XX Int. Dairy Congr.* Paper 50ST, 22 pp.

Kosikowski, F. V. (1981). *Tech. Lait.* **952**, 93, 95, 97.

Lang, F., and Lang, A. (1979). *Milk Ind.* **81**, (11), 30-1, 34.

MacBean, R. D. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 113-9, 128-30.

MacBean, R. D., Hall, R. J., and Willman, N. J. (1979). *Aust. J. Dairy Technol.* **34**, 53-9.

Mann, E. J. (1978). *Dairy Ind. Int.* **43**, (7), 31-2, 46; **43** (8), 55-7.

Mann, E. J. (1981). *Dairy Ind. Int.* **46**, (5), 25-6.

Marshall, K. R. (1979*a*). *N.Z. J. Dairy Sci. Technol.* **14**, 73.

Marshall, K. R. (1982). *CSIRO Food Res. Q.* **42**, 7-14.

Marshall, S. C. (1979*b*). *N.Z. J. Dairy Sci. Technol.* **14**, 103-8, 110-2.

Matthews, M. E. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 86-92, 96-102.

Maubois, J. L., Brule, G. and Gourdon, P. (1981). *Tech. Lait.* **952**, 29-33.

Morr, C. V. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 185-94, 201-4.

Muller, L. L. (1979). *N.Z. J. Dairy Sci. Technol.* **14**, 119-21.

Muller, L. L. (1981). *CSIRO Food Res. Q.* **41**, 37-43.

Muller, L. L., and Harper, W. J. (1979). *J. Agric. Food Chem.* **27**, 662-4.

Niroumand, K. (1978). *Milk Ind.* **80**, (4), 4-6, 10; **80**, (5), 5-7.

Spurgeon, K. R. (1976). *Cultured Dairy Prod. J.* **11**, (4), 8-13.

Stewart, J. A., Muller, L. L., and Griffin, A. T. (1974). *Aust. J. Dairy Technol.* **29**, 53-8.

Tobias, J., and Muck, G. A. (1981). *J. Dairy Sci.* **64**, 1077-86.

Wagner, K-H. (1980). *Dtsch. Molk. Ztg.* **101**, 1332-4.

Wit, J. N. de (1981). *Neth. Milk Dairy J.* 35, 47-64.
Zadow, J. G. (1979). *N.Z. J. Dairy Sci. Technol.* 14, 131-8, 141-2.
Zarb, J. M., and Hourigan, J. A. (1979). *Aust. J. Dairy Technol.* 34, 184-6.

News from the Division

Visiting Scientists

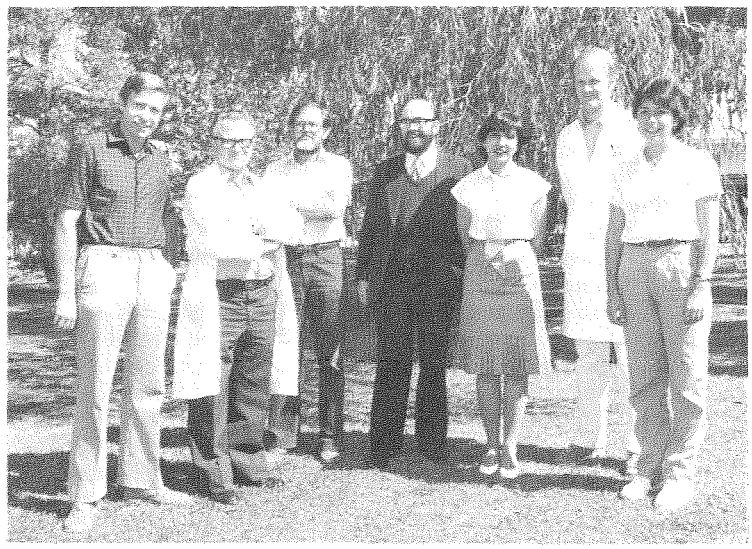
Readers will have noted some changes to this column over the past several issues. It no longer carries as much material about individual staff members as formerly, as this is available from the pages of the Division's Report of Research which appears around Christmas each year. Nor have there been any entries recently of new professional appointments. Regrettably, there have been very few such appointments and the Division is unable to fill most of the positions vacated due to retirement or other reason. This Division, along with many others in CSIRO, and, in fact, the entire public sector in Australia is still "contracting", due to the current recession.

So it is with some satisfaction to be able to report on the significant number of overseas scientists who come to work at the Division for periods ranging from several weeks to a year or more. FRL has in recent months been host to as many as 10 visiting workers at the one time, as detailed below. Seven of them are shown in the accompanying photograph.

Dr Colin Whitehead spent six months working with Dr Ross Hood on a project supported by the Australian Chicken Meat Research Committee. The project, with the goal of reducing fat deposition in broiler chickens, involved the measurement of lipogenic enzyme activities and very low density lipoprotein (VLDL) concentrations in plasma of chickens with large differences in food conversion efficiency and body fat content. The measurement of VLDL concentrations was found to be an appropriate method for identifying lean broilers.

Dr Whitehead is from the ARC Poultry Research Centre, Roslin, Scotland.

Professor Asher Ludin (Dept of Food Science, Central University of Venezuela, Caracas) studied the shelf-life and stability of commercially dried foods such as potato flakes, onion slices, vegetable soups and dessert mixes by storing the products at temperatures from 25° to 45°C. He was also interested in the critical moisture levels of



Recent visitors to FRL, from left to right: Dr Whitehead, Prof. Ludin, Dr Kopeliovitch, Mr Williams, Miss Al-Samarrai, Dr Fretheim and Miss Guedes.

commercially dried foods with respect to their organoleptic properties and stored the products at water activities from 0.1 to 0.53.

Non-enzymic browning of the potato and dessert mix was accelerated at the high temperatures and water activities.

Dr Ehud Kopeliovitch (Faculty of Agriculture, Hebrew University of Jerusalem, Rehovot, Israel) spent 12 months at FRL. He was supported by a Postdoctoral Research Fellowship from Israel and by a grant from the Sydney Farm Produce Market Authority for work on a Fresh Market Tomato Quality Improvement Project. Dr Kopeliovitch's work included field testing of advanced cultivars of tomatoes for the fresh market from his breeding program in Israel and laboratory studies on the physiology and biochemistry of fruit softening. Some of the Israel cultivars showed promise for Australian conditions and will be tested further.

Dr Kopeliovitch developed a new system for studying the *in vivo* regulation of polygalacturonase, the enzyme mainly responsible for softening of tomatoes during ripening. This system involves the extraction of cell walls from ripening fruit with the enzyme still bound thus enabling the testing of various treatments which affect the action of the enzyme on its natural substrate.

Mr A. P. Williams (The British Food Manufacturing Industries Research Association [BFMIRA] at Leatherhead, Surrey) spent three months studying the taxonomy of the food spoilage mould *Penicillium* with Dr J. I. Pitt.

Miss Makarim Al-Samarrai, UNIDO Fellow from the Iraqi Organization for Standards, Baghdad, studied a range of instrumental analytical techniques applied to food, including gas and liquid chromatography, mass spectrometry and atomic absorption spectrophotometry.

Dr Kris Fretheim (Norwegian Food Research Institute) has been participating in Dr R. W. Burley's work on the apoproteins of hen's egg yolk, specifically their complex formation with yolk lecithin. Complexes have been isolated and characterized after interaction in three different solvents. Work is now focused on gaining an insight into the precise mechanism of complex formation, with the aim of contributing towards the knowledge needed to bring protein-lipid interactions in food systems under control.

Miss Lúcia Guedes, UNIDO Fellow from the Institute of Food Technology, Campinas, Brazil, spent four months acquiring expertise in the area of food packaging, particularly the use of flexible films. She also attended two food industry packaging conferences, one in Tokyo, the other in Sydney.

Mr Nushirwan-bin-Zainnuddin (Malaysian Agricultural Research and Development Institute (MARDI), Penang, Malaysia), extended his knowledge of food engineering methods in FRL's pilot-scale processing area. He also accompanied Mr P. J. Rutledge on a field trip, visiting several food processors in N.S.W.

Professor James S. Todd of the Organic Chemistry Department of Whitman College, Walla Walla, Washington, U.S.A., spent about four months on sabbatical leave working here on biomimetic studies related to limonin, the bitter principle of processed citrus products.

Dr John T. Craig, a Senior Lecturer in Chemistry at Victoria University, Wellington, New Zealand, spent three months working in the Flavour Chemistry Section of the Laboratory with Dr F. B. Whitfield and Mr K. J. Shaw. Dr Craig's principal areas of interest during his visit were data acquisition and manipulation of mass spectra and the identification of volatile mould metabolites by combined gas chromatography and mass spectrometry.

Mention should also be made of another set of changing faces in the Division. The Australian Government's Special Youth Employment Training Program (SYETP) has provided many of our laboratories with keen and willing assistants for periods of 17 weeks. The program has proved to be of considerable mutual benefit.

International appointment

Mr Jack Kefford, Honorary Research Fellow and former Assistant Chief (External Relations) of the Division of Food Research, has been re-elected Secretary-General of the International Union of Food Science and Technology for a second four-year term.

IUFoST is a voluntary non-profit making association of national organizations, one from each country, each one representative of food scientists and technologists in that country.

Mr Kefford officially retired from CSIRO early in 1982 (see *Fd. Res. Q.* 42, No. 1).

Tour of Australian food industry by food technology students from France

A group of 16 students from France's École Nationale Supérieure de Biologie appliquée a la Nutrition et a l'Alimentation (ENS.BANA), on the campus of the University of Dijon spent about three weeks in Australia earlier in the year.

They visited some 15 food processing establishments on a 3000 km tour through N.S.W. and Victoria, as well as Hawkesbury Agricultural College and CSIRO. The tour was organized by Dr D. J. Casimir and Mr P. J. Rutledge of FRL. Dr Casimir had recently returned after spending one year as Associate Professor at ENS.BANA.

It appears likely that two of the students will return to Australia for about seven months to undertake a practical project at FRL as part of the requirement of their ENS.BANA course.

Food Technology Students from ENS.BANA, France, on their visit to FRL, flanked by Dr D. J. Casimir (far left) and Dr A. R. Johnson (far right), with Mr P. J. Rutledge at rear.

Consumer leaflet in Vietnamese

The Division's consumer service now has available a Vietnamese version of its well-known leaflet 'Handling Food in the Home'.

In addition to English, the leaflet has been published in Greek and Italian, with other languages planned.

Printing of the Vietnamese translation was assisted by the N.S.W. Branch of the AIFST's Food Microbiology Group and by Fairfield City Council, on the occasion of a food hygiene seminar attended by more than 100 Vietnamese food handlers.

About 60 000 Vietnamese have settled in Australia in recent years, approximately half of them in the Sydney area.

Gurcharan Singh Sidhu Animal Nutrition Centre

The Gurcharan Singh Sidhu Animal Nutrition Centre was inaugurated by Dr Sukhdev Singh, Vice-Chancellor of the Punjab Agricultural University, Ludhiana (India) on 25 January 1983 during a visit of Dr G. S. Sidhu of FRL to the university campus. This university was established after the partition of the Punjab State at the time of Indian independence. Dr Sidhu played an important role in establishing teaching and research facilities in the fields of biochemistry and animal nutrition whilst Head and Professor of Biochemistry there (1960–66). The building at the Centre was named in appreciation of the contributions made and direction provided by Dr Sidhu and his continued interest in its activities since 1966 when he joined the CSIRO Division of Food Research. The Centre has played an important role in improving the efficiency of poultry and large animal production in north-western India.

The ceremony at Punjab Agricultural University, from left to right: Dr and Mrs G. S. Sidhu, Dr Sukhdev Singh (Vice-Chancellor), Dr S. S. Gill (Professor and Head of Dept of Animal Husbandry) and Dr K. S. Gill (Dean, College of Agriculture).