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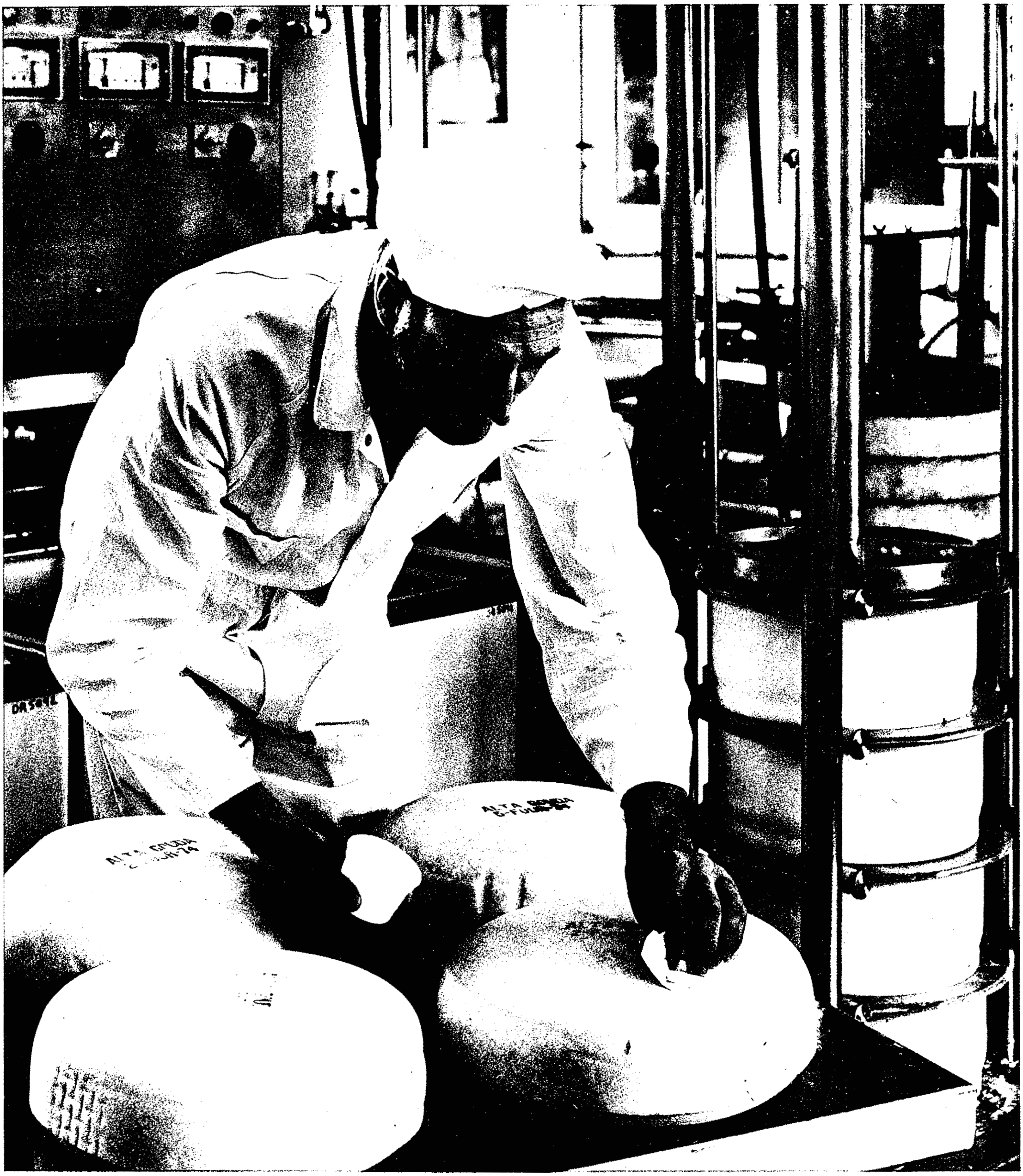

'One man's meat . . .'

By M. V. Tracey

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The nutritional hazards in some components of normal foodstuffs. Adapted from a talk given at a symposium on food hazards organized by the South Australian Division of ANZAAS, March 1973

Each of us will die. Some who might have been here today have died already. If we all had the resistance to stress, injury and disease which we had at the age of ten, about half of us here today might expect to be alive in 700 years' time. But our powers of self-adjustment and self-maintenance decline with the passage of time and finally decline very rapidly indeed, and the probability of disease and death increases. It is possible that a minor factor increasing the steady pressure away from health towards disease and inevitable death lies in the food we eat, and it is my concern in this article to attempt to identify some of these minor hazards which may play a small role in hastening our passage to the grave and perhaps in rendering it a less pleasant experience than we might hope it to be.

The hazards I wish to consider can be conveniently divided into two classes, the adventitious and the intrinsic. Much is known of those in the former class and much, perhaps too much, has been written about them; they are the subject of public and legislative concern and present a real problem which fortunately carries with it a solution simple in principle. If something harmful is added to food either by accident or misguided design, the solution is to stop adding it. Real though the adventitious hazards resulting from man's ingenuity are, they are not the subject of this article and I shall discuss them no more.

Intrinsic hazards

In most instances the distinction between the intrinsic and adventitious can be clearly made. In a few it is more difficult, and it is in these that the legislative pen may be quite powerless or indeed irrelevant. We cannot successfully or fruitfully legislate against nature—if the natural zinc content of beef, mother's milk and Camembert cheese happens to be higher than that permitted in legislation, we must accept that the legislation, while based on the best advice available at the time it was framed, is now irrelevant and must be revised in accordance with newer knowledge of food composition. There is, in fact, a strong case that all regulations controlling the presence of individual compounds in food should be interim in effect and subject to constant review as increased knowledge enables better judgments to be made.

The intrinsic hazards are components of food which are always present however the food is produced or processed. These hazardous agents can conveniently be divided in classes—the proteins, carbohydrates, nucleic acids, fats, vitamins and minerals. To these can be added the small number of naturally occurring carcinogens, mutagens and teratogens in some foods. My topic, then, is natural toxins in natural foods.

In considering natural toxins in natural foods, that is, in foods normally and traditionally eaten by mankind or a significant part of mankind, we must distinguish between those which are toxic to all who consume them and those which affect only some. Naturally a product of nature is regarded as a food only if it has become obvious that no harm arises from its consumption. For such harm to exclude it as a food, its injurious effects must, of course, have been clear and immediate, becoming obvious within a few days of consumption. Long-term toxic effects of foods over a period of years are only just becoming known, and of cumulative ill effects taking half a century for expression less still is known, though there is evidence that these exist.

Occasional toxicity in foods

In spite of a food being harmless by definition it happens that some foods are toxic in some circumstances, and here I am excluding the adventitious toxicity due to microbial action or accidental contamination with toxic agents. The longest-known example of sporadic toxicity in a human food is perhaps in honey, since the first account of widespread poisoning by such means is that of Xenophon in the *Anabasis*. He describes how in 400 BC the 10 000 Greek mercenaries of Cyrus fighting their way back to Greece after being abandoned near Babylon came in sight of the Black Sea and shortly afterwards took up quarters in a group of well-provisioned villages. 'Now for the most part there was nothing here which they really found strange; but the swarms of bees in the neighbourhood were numerous, and the soldiers who ate of the honey all went off their heads, and suffered from vomiting and diarrhoea, and not one of them could stand up, but those who had eaten a little were like people exceedingly drunk, while those who had eaten a great deal seemed like crazy, or even, in some cases, dying men. So they lay there in great numbers as though the army had suffered a defeat, and great despondency prevailed. On the next day, however, no one had died, and at approximately the same hour as they had eaten the honey they began to come to their senses; and on the third or fourth day they got up, as if from a drugging.' This episode was due to the fact that rhododendrons are abundant in the neighbourhood and the bees had been collecting the nectar which contains andromedotoxin, which also occurs in azaleas, oleanders and the dwarf laurel. Similar examples of toxic honey have been reported in recent years from Turkey, the U.S.A., Canada and New Zealand, though the toxin concerned was not the same in all instances.

Another food which may exhibit sporadic natural toxicity is milk—Abraham Lincoln's mother is said to have been killed (as had a great-aunt, great-uncle and a cousin once removed!) by drinking milk from a cow that had fed on snake-weed, whose milk consequently contained the toxin tremulin. Bracken contains a compound with both mutagenic and carcinogenic properties which will pass into the milk of a cow eating the plant, but no instances of human cancer have been reported from this possible cause. Finally, I might mention the recent furore in Britain where it has been suggested that a proportion of the cases of spina bifida in the newborn might be due to the consumption during pregnancy of potatoes infected with blight.

Natural carcinogens

We worry rightly lest our food should contain adventitious toxic material, and in the U.S.A. legislation exists forbidding the addition to foods at any level of any substance that has been shown to cause cancer at any concentration or by any route of administration in animals. This is an attempt to safeguard man in affluent societies from the hazards of misapplied technology, and we tend to assume that such hazards cannot exist for man living closer to a state of nature—that state defined by Hobbes in 1651 as 'No arts; no letters; no society; and which is worst of all, continual fear and danger of violent death; and the life of man, solitary, poor, nasty, brutish, and short'. Only four compounds are known at present which are so violently and certainly carcinogenic that they will cause cancer in animals as a result of a single dose. None is a synthetic product; all four occur in foods consumed by men living in a relatively primitive state and choosing their foods in accordance with their own social tradition. These instances occur among the Bantu of South Africa, in West African tribes and among the natives of Guam.

They are perhaps worth description. The first is familiar to many—one of the aflatoxins frequently produced by strains of *Aspergillus flavus* when growing on peanuts and some other stored products. Aflatoxin B_1 is the most poisonous—$\frac{1}{2}$–10 mg/kg body weight is the range of LD_{50} for most experimental animals. LD_{50} is that dose which will kill half the animals exposed to it. Liver tumours result in rats from a single dose of 5 mg/kg body weight and from the presence of less than 0·3 p.p.m. constantly present in the diet. Strictly speaking, aflatoxin is adventitious, but it occurs naturally in stored foods in tropical climates and presumably has so occurred throughout agricultural history in these areas. Its existence was only recognized in 1960 when a large number of turkeys and ducks died as a result of the inclusion of mouldy peanuts in their diet. It is reasonable to suppose that millions of people have been exposed to this hazard in the past, and it is well known as an ever-present risk today which must be actively guarded against.

My second example is one of the pyrrolizidine alkaloids. More than 100 are known, occurring mainly in the widely distributed plant genera *Senecio*, *Heliotropium*, *Cynoglossum* and *Trichodesma*. Many are carcinogenic in animals, and one from *Senecio* species called retrorsine has the distinction of causing liver cancer in rats after a single dose of 30 mg/kg. Plants of these species are not normally used as foods, but in Africa they are widely used as medicines—particularly for sick children. The juice of *Crotalaria*, for example, is applied to the skin in cases of measles in East Africa and the plant is also used in 'bush teas' in Jamaica. After an educational campaign against the practice of using the plants as medicaments, the incidence of liver disease in children was reduced.

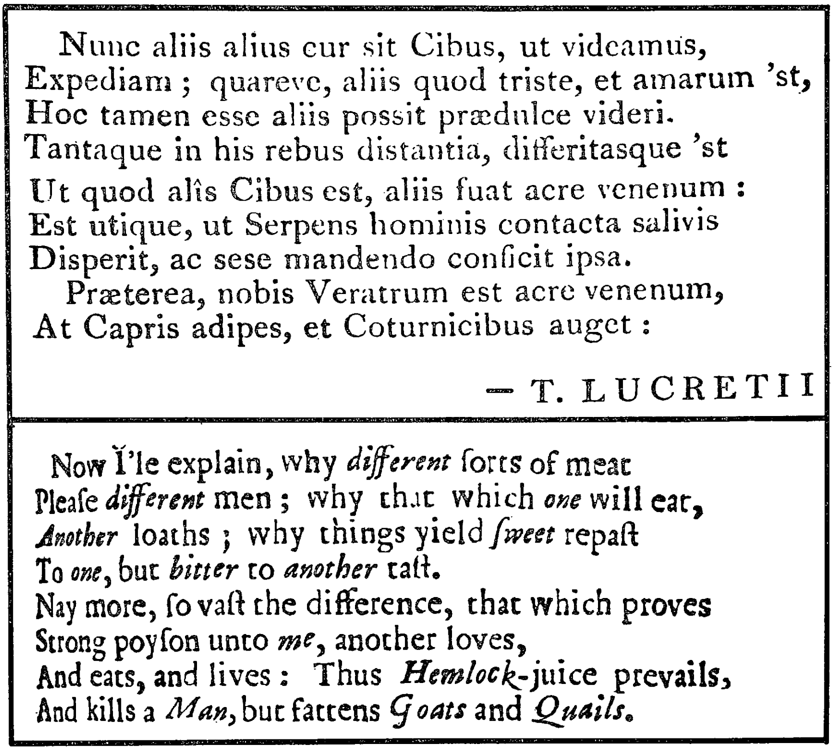
The third carcinogen, dimethylnitrosamine, also occurs in some African foods and is almost certainly responsible for some cancer in man. While it also can be found in minute traces in some traditional foods of western civilization, there is no evidence at present that these levels are significant. In some villages of Bantu tribesmen living in the Transkei a hundred kilometres or so north of East London, cancer of the oesophagus, a rare disease, is unusually prevalent. Since it prevails only in some villages and not in others, it aroused interest. It was found that where the disease occurred there were also signs of molybdenum deficiency in the leaves of many of the food plants. In villages where the disease did not occur, signs of molybdenum deficiency were absent. Now if a leaf is deficient in molybdenum, there is an accumulation of nitrate in the leaf, and if the leaf is chopped or ground, nitrate is reduced to nitrite and this in turn will react with secondary amines to form nitrosamine. To cut a long story short, dimethylnitrosamine was identified in milk curdled with the juice from the crushed green fruit of a solanaceous bush. Milk curdled in this way is the chief source of food for the men during the day. It is obvious how difficult it is to generalize in these matters, for it seems clear that this particular food may contain a carcinogen only if it is prepared in an area where the soil is deficient in molybdenum.

Finally there is the case of cycad nuts in Guam. The nuts contain a glycoside, cycasin, which is harmless to eaters if they have no microorganisms in their gut, for their own enzymes will not hydrolyse it to the carcinogen methylazoxymethanol. Unfortunately guts do contain bugs and the carcinogen is released. The Guamese eat large quantities of flour prepared from the nuts but the method of preparation involves a thorough washing of the pounded nut with water, thus removing the cycasin and the source of the carcinogen. This appears then to be an example of primitive wisdom—or some would go so far as to call it an instinct. Such reliance on primitive wisdom is rendered a little less consoling when we learn that the popular treatment for ulcers was to rub fresh juice from the nut onto the exposed tissue where it would certainly be hydrolysed by bacteria with release of the carcinogen.

Chronic poisons

You may feel that so far I have mentioned only toxic foods so rare or consumed by people so remote from us as to be essentially irrelevant. There may be some weight in such a comment, but I wish to stress the point that because a plant or animal product is used as a food, one cannot assume that, provided nothing is added to it, it must be harmless. If some 'natural' foods can be acutely toxic, there is the possibility that some, perhaps many, may have chronic toxicity. There is much epidemiological evidence that peoples living in different areas tend to have different disease experience. For example, liver cancer in Africans living in Johannesburg is five times as frequent as in blacks of a similar origin living in the United States, while those living in Africa have a lower incidence of gastrointestinal cancer. Endomyocardial fibrosis, rarely seen in advanced countries, is relatively common in Africa, as is periportal fibrosis of the liver. In contrast, coronary heart disease, gall-stones, rheumatoid arthritis and disseminated sclerosis are rare in Africans in Africa but not among their cousins in the United States. I am not suggesting that in all these instances there is a dietary cause in the form of food toxins, though it is the most likely explanation for the high level of liver disorders in Africa. But there does seem a strong likelihood that diet can predispose to a variety of disease, and that one might in the future be able to modify Brillat-Savarin's remark in 1825, 'Tell me what you eat, and I will tell you what you are' to 'Tell me what you eat, and I will tell you what you are likely to die from.'

nutritionally—and this, too, is an old truth. Lucretius, in addition to writing compellingly on the atomic theory of matter, said at the time of the Roman invasion of Britain, *Ut quod aliis cibus est, aliis fuat acre venenum*—'What is food to some is bitter poison to others'. He went on to give as an example the observation that hellebore is poison to us but fattens goats and quails. Some nutritional inequalities may result in a component of the diet, harmless to most men, being toxic for an individual. The first and most familiar example is, of course, the diabetic, though it had long been suspected that there was a link between diet and gout. It would be possible to discuss at some length the mortal and chronic diseases of man induced by his diet but it seems to me more appropriate here to approach the relationship from the point of view of the components of a normal diet believed to be harmless to the consumer which can cause disease in some of those who consume it.



Nunc aliis alius cur sit Cibus, ut videamus,
Expediam ; quareve, aliis quod triste, et amarum 'st,
Hoc tamen esse aliis possit prædulce videri.
Tantaque in his rebus distantia, differitasque 'st
Ut quod alîs Cibus est, aliis fuat acre venenum :
Est utique, ut Serpens hominis contacta salivis
Disperit, ac sese mandendo conficit ipsa.
Præterea, nobis Veratrum est acre venenum,
At Capris adipes, et Coturnicibus auget :

— T. LUCRETII

Now I'le explain, why *different* ſorts of meat
Pleaſe *different* men ; why that which *one* will eat,
Another loaths ; why things yield *ſweet* repaſt
To *one*, but *bitter* to *another* taſt.
Nay more, ſo vaſt the difference, that which proves
Strong poyſon unto *me*, another loves,
And eats, and lives : Thus *Hemlock*-juice prevails,
And kills a *Man*, but fattens *Goats* and *Quails*.

T. Lucretius Carus, *De Rerum Natura*, 'done into English verse' by Thomas Creech, Oxford, 1682.

'One man's meat . . .'

In discussing the wholesomeness or otherwise of food, it is all too easy to think of a variety of foods differing in their properties or composition being eaten by the entity, Man. Man can be considered as an entity only in strictly defined and qualified circumstances. All men are regarded as being born equal in respect of certain rights and demands offered and imposed by society. They are demonstrably not born equal in eye colour, pigmentation, intelligence or stature. The same is true

Proteins

We know that proteins are an essential component of any diet for man. Their essential role is recognized because it has been demonstrated experimentally that a number of the amino acids of which they are composed and into which they are broken down on digestion could not be synthesized by the small number (some dozens) of men and women who were subjected to controlled experimentation for some weeks. Our confidence that these essential amino acids are essential for all men is increased by the results of far more extensive animal experimentation. It comes as a surprise, therefore, that the consumption of a diet containing a normal amount of protein with the usual component essential and non-essential amino acids can lead to idiocy and a shortened life-span in some individuals owing to the presence of toxic amounts of an amino acid essential for man.

In this disease, phenylketonuria, dietary phenylalanine is used normally in protein synthesis but an excess, instead of being metabolized in the normal way, is converted to phenylpyruvic acid, a compound not readily broken down and whose presence at appreciable levels in the blood results in severe mental retardation. This effect on the brain may be obviated if the condition is identified at birth and if from then on the intake of the essential amino acid phenylalanine is restricted to about one-third of that present in the protein of a normal diet. About 400 phenylketonuriacs are born each year in North America, and in Australia about two dozen. The disease is dramatic in that consumption of a normal amount of protein leads to severe mental retardation; it is not unique, for protein restriction in the diet has been employed in the treatment of at least ten other conditions in which the body is unable to handle a normal intake of amino acids. Far commoner than these diseases is a form of coeliac disease, which can be completely relieved by excluding from the diet the storage protein, gluten, of wheat and rye.

Carbohydrates

Diabetes is not the only disease in which the carbohydrate content of the diet must be carefully controlled. Intolerances exist for galactose, fructose and some disaccharides as well. Of these intolerances, that for lactose may be of importance for Australia's exports of milk products. There is evidence that consumption of lactose in many adult Asians may lead to intestinal unease—a phenomenon that readily leads to marked resistance to the consumption of dried and reconstituted milks. In galactosaemia, death may occur a few weeks after birth, in the absence of treatment by exclusion of galactose and lactose from the diet. Mild untreated cases may result in mental retardation and blindness.

Professor Yudkin (1972) has discussed the possible deleterious effects of sucrose as a dietary component. In Western countries it is the source of 15–20% of the energy content of the diet, though two centuries ago it accounted for only 1–2%. Yudkin suggests that a high intake of sucrose may increase the incidence of dental caries, chronic dyspepsia, seborrhoeic dermatitis, diabetes, ischaemic heart disease and gout.

Nucleic acids

Dietary reduction of the intake of nucleic acid in the food is commonly used as an adjunct to the treatment of gout by other means. The primary predisposing cause of gout, however, seems to be excessive endogenous production of purines. There is currently some concern that the high nucleic acid content of fungi and yeasts may, if they are introduced on a major scale as a source of protein ('single cell protein'), lead to an increased incidence of gout.

Fats

There is no doubt that victims of coronary heart disease as a group have a higher than normal level of cholesterol in the blood, and the same relation is becoming apparent in connection with blood triglyceride levels. A major determinant of increased blood cholesterol levels and blood triglyceride levels is the content of saturated fatty acids (particularly palmitic acid) in the diet. The lipid-raising effect of the saturated fatty acids is opposed by the polyunsaturated fatty acids, and dietary cholesterol also has an effect on the final blood level. The greatest rise in serum cholesterol level results from a diet rich in both saturated fatty acids and cholesterol. A combination of saturated fatty acid and sucrose may also lead to striking rises in blood triglyceride levels. The extent of these effects varies between individuals and is in some instances genetically determined. Both cholesterol and triglyceride levels can be reduced by lowering cholesterol intake and by increasing the proportion of polyunsaturated fats in the diet. There is no doubt that for a significant part of the population certain lipids normally present in foods may increase the likelihood of disease and death.

Vitamins

Disease can, as is well known, be caused by over-dosage of the fat-soluble vitamins A and D, and is sometimes seen in infants as a consequence of over-liberal supplementation of the diet with vitamin concentrates by mothers unaware of the danger. It is less well known that it can also occur from the consumption of food with a high content of vitamin A. During the 1939–45 war there was at least one instance in England of hypervitaminosis A due to the over-enthusiastic consumption of carrots, and there are well-attested instances of poisoning, resulting in intoxication and severe illness, after eating the liver of polar bears (the first report dates from 1596), shark and halibut. Of more general importance, perhaps, is the number of sources of antivitamins which include antagonists of A, two of the B group, D and E. There are no reports of an antivitamin C. The variability of man is again of importance in that some very rare individuals require for normal health a regular intake of 10 to 200 times the normal requirement of some of the B vitamins.

Minerals

Minerals occur in drinking-water that has not been polluted and has not acquired them from piping and other non-natural sources. As far as we know, the qualitatively and quantitatively important elements in drinking-water include calcium, sodium, silicon, magnesium, fluorine, boron, manganese, aluminium and iodine. There is a negative correlation in some countries, but not in Australia, between the death rate from heart disease and the hardness of water, and to a lesser degree between water hardness and death from bronchitis. No such correlation either negative or positive has been found between hardness of water and other common causes of death.

Conclusion

I believe that I have said enough to support my thesis that there is clear evidence that normal components of normal foods may have a considerable effect in causing disease in individuals, some groups of susceptible individuals being very small indeed, others representing a significant proportion of the population. There are two sets of circumstances in which such correlations between disease and dietary constituents may be identified. The first occurs when the disease is acute or its onset is sudden, and quite simple manipulations of the diet can point to the connection. In the other circumstance, for example in the case of cardiovascular disease with its multiple causation, the disease must be widespread enough to justify elaborate statistical examination of the situation. It is fair to say that at present we have no way of knowing whether a particular component of the normal diet may shorten life expectancy by, say, 10 years or so, or if its effect is no more than accelerated senescence or an increase in the rate of diminution of our capacity to resist the assaults of the environment. We eat and drink a lot before we die. Most of us can expect to have consumed some 12–13 tonnes of dry matter and about 50 tonnes of water in our lifetime. If a deleterious material is present in our food or water at a level of one part per million, we will have ingested 12–13 grams in our food and 50 grams in our water. Fortunately, most toxins are not cumulative, they are normally either broken down in the body or rapidly excreted, but this is not true of all of them.

While we can assume that the foods of our forefathers will be satisfactory for the majority of individuals, it would be dangerous to assume that they represent an ideal to be aimed at. I believe there is much to be learnt of human nutrition, particularly in the relation between nutrition and long-term effects on health, and that our proper concern to avoid toxins or conceivable toxins being added to our foods by accident or design should not inhibit us from a vigorous effort to learn more of the intrinsic hazards of our food. In this effort it will, of course, be essential to bear in mind always that it is the individual who suffers from a disease, and that each of us is an individual born nutritionally unequal to his fellows.

Reference

Yudkin, J. (1972). 'Pure, White and Deadly; the Problem of Sugar'. (Davis-Poynter: London.)

Freeze-drying

Two articles based on talks given at the recent Convention on Freeze-drying, Armed Forces Food Science Establishment, Scottsdale, Tasmania

I. The CSIRO process for cyclic freeze-drying

By J. Middlehurst

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One of the most ancient ways of preserving food is to dry it. Removing the water has several advantages: no water is available for the growth of food spoilage organisms and the weight, and often the volume, are considerably reduced. Drying a food while the water in it is still liquid yields a product that has undergone shrinkage and often has developed a hard skin. Both of these defects lead to difficulties when an attempt is made to reconstitute the food, i.e. to put the water back into the food before it is eaten.

Cyclic freeze-drying is a new process (Fig. 1), developed in Australia, for the preservation of food. It is the logical development of conventional constant-pressure freeze-drying and permits much higher production rates for a given size of drier. As yet there are only two commercial-scale units for cyclic freeze-drying available in the world, one in Sydney and one at Scottsdale in Tasmania.

The purpose of this article is to give a brief description of conventional freeze-drying, to discuss its limitations, and to show the way in which the cyclic process overcomes them.

Editor's note: All measurements in the text of articles are now expressed in metric units and imperial equivalents are no longer given. However, the unit conversion factors for any unusual metric units appearing in an article will be listed in a footnote, to help readers familiarize themselves with the metric system, i.e. le Système International d'Unités (SI). The following are the conversion factors for some metric (SI) units used in this article:

$1\ \mathrm{kg\ s^{-1}\ m^{-2}} = 736\ \mathrm{lb/(hr)\ (ft^2)}$

$1\ \mathrm{kW\ m^{-1}\ K^{-1}} = 6{\cdot}9\ \mathrm{Btu/(hr)\ (ft^2)\ (^\circ F/in)}$

$1\ \mathrm{Pa} = 1{\cdot}45 \times 10^{-4}\ \mathrm{lb/in^2}$

Conventional freeze-drying

The process of freeze-drying was devised in an effort to dry foods in a truly reversible way so that the water could be returned easily and the reconstituted food would have the same flavour, texture and nutritive value as it had before preservation. The process goes a long way towards achieving its goals but the removal of water is not

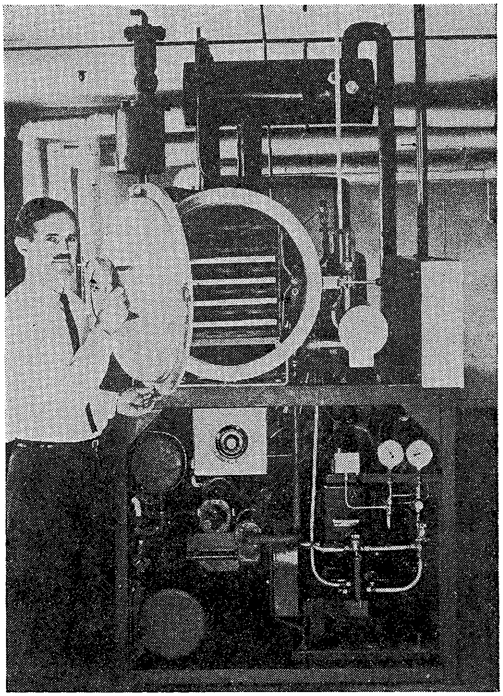

Fig. 1. Mr J.D. Mellor, Senior Research Scientist at the Food Research Laboratory, with the CSIRO pilot-scale cyclic freeze drier. Mr Mellor developed the process of cyclic freeze-drying.

entirely reversible and some foods show a detectable loss of flavour.

Freeze-drying consists of freezing the food to a temperature of $-20°C$ to $-40°C$ and then subliming the ice directly to water vapour in a vacuum chamber, taking great care that the ice is never melted during the process. The main cause of shrinkage during drying in air or in heated air is the surface tension of the liquid water in the food. By keeping the water frozen during the whole drying process, this force no longer exists and the food maintains its shape.

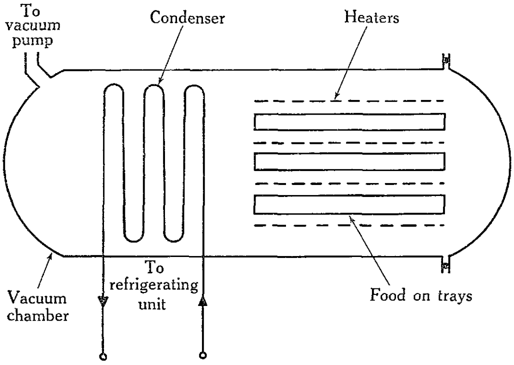

Fig. 2. Typical freeze-drying unit.

Figure 2 shows the basic machinery necessary for freeze-drying. The purpose of the condenser is to remove the water vapour from the vacuum chamber and so maintain a low water vapour pressure, and also to prevent water vapour from getting into the vacuum pump. The heaters provide the energy necessary to cause the ice to sublime.

Limitations

Because of the machinery involved, freeze-drying requires a large capital outlay. Consequently, much effort has been put into studying the factors limiting the rate of production, i.e. the rate of drying. Figure 3 shows a somewhat simplified representation of a cross section of a piece of food that is partly freeze-dried. It consists of a frozen core with a dried layer surrounding it. The outer surface of the frozen core is termed the ice interface.

To convert 1 kg of ice at $-20°C$ to water vapour requires approximately 2·5 MJ of energy. This energy must flow from the heaters to the ice interface. The rate at which the energy can be supplied is limited by the maximum temperature that the outer surface of the dried layer can withstand, the thermal conductivity of the dried layer and the temperature of the ice interface.

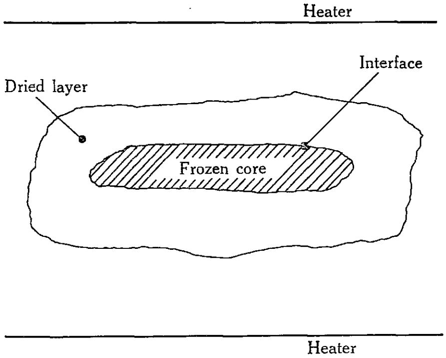

Fig. 3. Representation of food being freeze-dried.

For an interface temperature of $-20°C$,

$$S = (k/2500)\,[(T_m + 20)/d]\ \mathrm{kg\,s^{-1}\,m^{-2}}, \quad (1)$$

where S = sublimation rate ($\mathrm{kg\,s^{-1}\,m^{-2}}$),
T_m = maximum surface temperature (°C),
k = thermal conductivity of dried layer ($\mathrm{kW\,m^{-1}\,K^{-1}}$),
d = thickness of dried layer (m).

For freeze-dried meat for which
$k = 35 \times 10^{-6}\ \mathrm{kW\,m^{-1}\,K^{-1}}$,
this gives
$S = 14 \times 10^{-9}\,[(T_m + 20)/d]\ \mathrm{kg\,s^{-1}\,m^{-2}}$.
If $T_m = 60°C$ and $d = 5$ mm,
$S = 0{\cdot}22 \times 10^{-3}\ \mathrm{kg\,s^{-1}\,m^{-2}}$.

Equation (1) establishes the maximum rate at which energy can be supplied. Since for porous solids in a vacuum k is very low, S is necessarily small.

The second limitation to ordinary freeze-drying is the rate at which water vapour can be removed from the interface. This vapour diffuses out through the dried layer to the vacuum chamber and thence onto the condenser. The rate at which the vapour is removed is given by

$$R \propto [D\,(P_I - P_V)/d]\ \mathrm{kg\,s^{-1}\,m^{-2}}, \quad (2)$$

where R = diffusion rate ($\mathrm{kg\,s^{-1}\,m^{-2}}$),
D = diffusion coefficient ($\mathrm{m^2\,s^{-1}}$),
P_I = vapour pressure at the ice interface (Pa),

P_V = vapour pressure at surface of dried layer (Pa),
d = thickness of dried layer (m).

During ordinary freeze-drying a balance is achieved such that $R = S$, i.e. the ice is sublimed at just the rate at which the resultant water vapour is removed.

If the process is to be speeded up it is necessary to increase R and S simultaneously, and this can be done most easily by reducing d. If the food to be freeze-dried can be granulated, either before or after freezing, the freeze-drying rate is markedly increased. For example, coffee takes 10–12 h if freeze-dried in a slab 20 mm thick but this time can be reduced to 10–20 min for granules 2 mm in diameter.

For foods that cannot be granulated or cut into thin slices it is difficult to increase the rate of freeze-drying. If the pressure in the chamber is reduced by using a faster pump, P_V is also reduced so R increases, but k and consequently S decrease. At high chamber pressures k increases but D decreases as shown in Figure 4. So there is no real way of optimizing the rate of freeze-drying because equations (1) and (2) must be optimized simultaneously.

Cyclic freeze-drying

In cyclic freeze-drying (Mellor 1969) the processes represented by equations (1) and (2) do not occur simultaneously and so each can be optimized separately. The process consists of letting a gas having a high thermal conductivity into the vacuum chamber for a short time, usually 1–3 min, and then pumping out the gas and the water vapour for a short time, again 1–3 min, and repeating this cycle of alternate high and low pressures until the material is dried. During the high-pressure part of the cycle, the thermal conductivity k can be made large and the energy flow is large. However, D is small, so there is no removal of water vapour. Instead of the ice subliming, the temperature of the interface rises. As soon as the chamber pressure is lowered there is a rush of gas and water vapour out of the chamber. The ice interface sublimes rapidly and its temperature falls. The interaction of the various temperatures and pressures can be seen from Figure 5. The cold vapour rushing through the porous layer cools it down rapidly and the surface temperature falls. The rate of sublimation

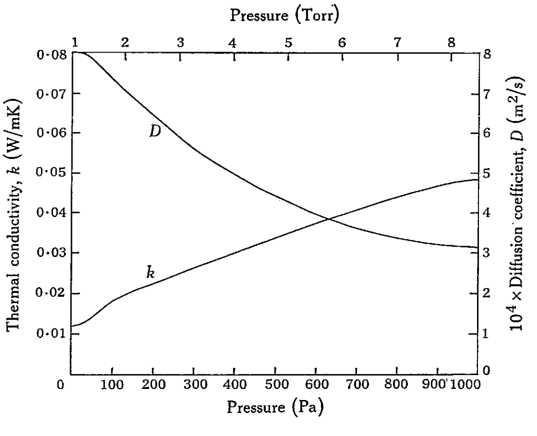

Fig. 4. Thermal conductivity k and diffusion coefficient D v. pressure, in turkey meat during freeze-drying.

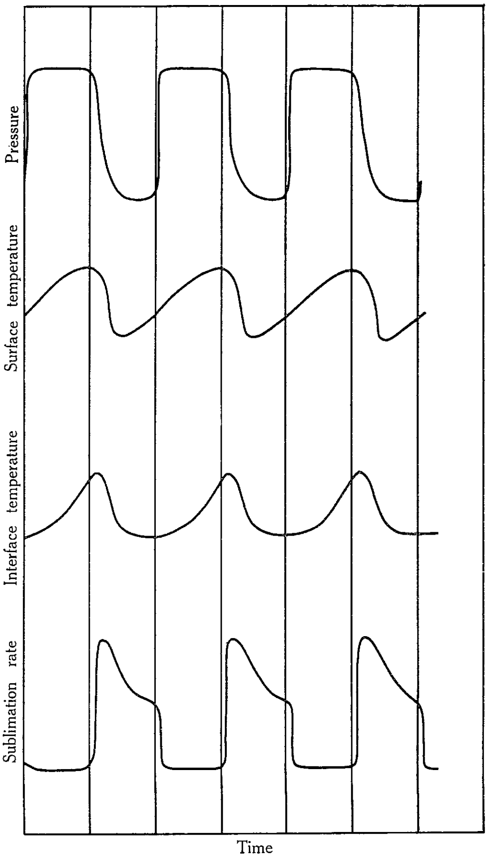

Fig. 5. Operating parameters in cyclic freeze-drying.

shows a sharp peak followed by a decay, and for each product there is an optimum amount of decay that will give the maximum overall rate of freeze-drying.

At the start of freeze-drying it is not necessary to use the cyclic process since d is small and so S is large. However, once d becomes greater than about 1 mm the cyclic process increases the rate of freeze-drying. The times t_1 for which high pressure is applied and t_2 for pumping vary with the product and with the stage of the freeze-drying process; both t_1 and t_2 need to be longer as the drying approaches completion.

The overall gain in sublimation rate to be achieved by cyclic freeze-drying can be seen from Figure 6. If at the end of the low-pressure part of the cycle the gas is not admitted to the chamber but the pumps are left on, the process reverts to conventional freeze-drying as indicated by the broken line. The total mass sublimed in time $t_1 + t_2$ during conventional freeze-drying is obtained by measuring the areas indicated on the right-hand side of Figure 6. The total mass sublimed in time $t_1 + t_2$ during cyclic freeze-drying is simply the area of the left-hand peak. By superimposing the rectangular areas on the peak it can be seen that the peak has a larger area, the excess area being dotted in the diagram.

When nitrogen is used as the high-conductivity gas, at a pressure of about 1·3 kPa, the freeze-drying time is reduced by about 30% compared with conventional freeze-drying. Using helium at about 10 kPa, the time is reduced by about 45%. Figure 7 compares the freeze-drying of beef steak 15 mm thick using the conventional process with the freeze-drying of similar steak by the cyclic process. There is a marked improvement in the rate of drying for end products of similar quality.

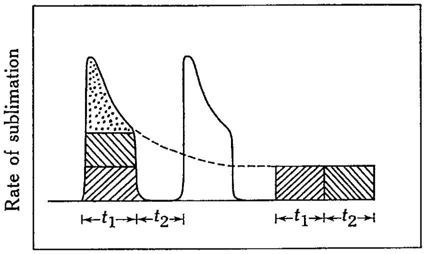

Fig. 6. Gain achieved by cyclic freeze-drying.

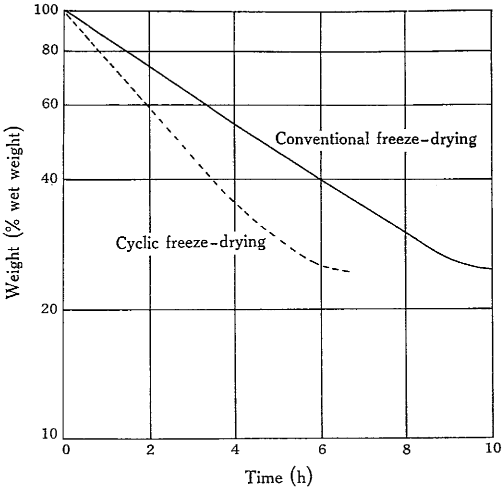

Fig. 7. Drying rate for beef-steak.

Quality of the product

A wide range of foods has been successfully dried by the cyclic freeze-drying process and with a few exceptions the quality of the reconstituted product is little different from that of the original; some meats tend to become stringy when freeze-dried by either method. Some particularly sensitive products need very long drying times by either the conventional or cyclic freeze-drying process. The cyclic process is always about 30% faster for the same quality of product; by running the cyclic process for the same time as the conventional process and taking advantage of the much lower surface temperature that may be used with this method, a product of superior quality may be obtained. In this way one can trade rate of production for improved quality if this is desirable for particularly sensitive products.

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Freeze-drying

II. Effects of the process on the product

By J. F. Kefford

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When a food technologist dehydrates a food he may cherish the naïve hope that by putting the water back he will reconstitute the food in its original form. He cannot, however, remove water from a food without bringing about other changes. There are changes in the nature of the food on dehydration that are not reversible by the restoration of water, and water cannot be removed without removing some other volatile constituents, particularly those contributing to aroma. Since changes of both kinds are aggravated by heat, freeze-drying should minimize them because in this process water is removed from foods at low temperatures. The changes, however, cannot be entirely avoided. The purpose of this article is to review what happens to a food during freeze-drying.

Changes during freezing

Removal of water from a food that is to be freeze-dried commences in the freezing operation, when the water crystallizes out of the system as ice. Even at this early stage, mechanical pressure caused by the greater volume of the ice may lead to some denaturation of protein. If large crystals form, cell walls may rupture, cell components may mix and react and enzymes may have access to free substrates. The rate of freezing is therefore an important variable in freeze-drying technique. For products with cellular structures which must be maintained, fast freezing seems to be indicated, to ensure that the crystals will be small and so minimize cell damage. But on the other hand, many foods show best reconstitution after slow freezing, presumably because large ice crystals form large holes in the porous structure for re-entry of water and escape of air. So the best rate of freezing for a particular product must be determined by compromise.

When water is removed from the foodstuff as ice, concentrated solutions of solutes are formed, and these may be potential causes of chemical injury to the food: for example, if the system is not well buffered there may be significant changes in pH.

The concentrated solutions are distributed through the frozen food in unfrozen or eutectic zones. In addition to these unfrozen zones, there is in foodstuffs so-called 'unfreezable water', i.e. water which appears not to freeze because it is bound to food constituents in specific ways. Water molecules bound to strongly polar sites on the food by hydrogen bonds of relatively high energy are often referred to as the monomolecular layer, although this term is misleading. Several successive layers of water molecules beyond this one may still be 'unfreezable' but are bound with decreasing binding energies.

Changes during drying

The foods that have been studied most intensively as to their behaviour during freeze-drying are raw meats and fish, probably because they are the most difficult to treat successfully. When raw meat or fish is freeze-dried, then reconstituted and cooked, the products tend to be tougher and less juicy than control samples.

After reading the literature on the freeze-drying of meat, I am convinced that workers in this area have been led on by the vision of a freeze-dried steak that could be reconstituted and grilled to a state of rare tenderness; but this is an impossible goal. Greater success has been achieved in the freeze-drying of cooked meats.

Even at the low temperatures used in freeze-drying some denaturation of muscle proteins occurs. If we measure denaturation in terms of loss of solubility in salt solutions under standard conditions, then about 25% of myosin in beef appears to be denatured during freeze-drying, and about 50% of myosin in fish.

It is not easy, however, to explain the

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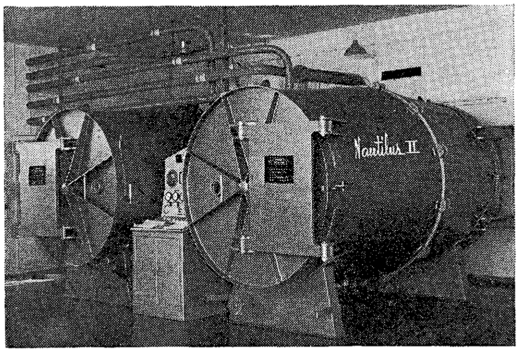
unsatisfactory texture of reconstituted freeze-dried meats solely in terms of denaturation. There are, in addition, changes in structure or binding of proteins which make it difficult to restore water molecules to all the sites from which they were removed during drying.

The changes that occur in the proteins of meat products during freezing and drying will continue in storage at rates that depend greatly on the residual moisture content and storage temperature.

Shrinkage

When foods are dried by conventional air-drying techniques, one of the most obvious phenomena is shrinkage and change of shape. As water is withdrawn from the foods during drying, surface tensions cause progressive contraction and distortion of cellular structures. In freeze-drying, however, shrinkage is absent or minimal because the ice provides mechanical support for the tissues during the sublimation stage, and in the absence of liquid water there are no surface tensions. So freeze-dried foods characteristically show open porous structures in which the integrity of the original form is well preserved.



A conventional commercial-scale freeze-drier.

Rehydration

An important consequence of the porous structure of freeze-dried foods is their ease of rehydration compared with other dried foods. In fruit and vegetable tissues, especially, the ease of rehydration is closely correlated with retention of an intact cellular structure which, as already mentioned, depends on the rate of freezing. In some products, notably peas, it is necessary to puncture the outer skin to permit entry of water for rehydration. Freeze-dried fruit and vegetable products retain their rehydration properties in storage rather better than the high-protein foods.

It has been reported that a single muscle fibre rehydrates in three seconds, but the time necessary for rehydration of pieces of meat depends on how quickly water can penetrate by capillary action, aided by the wetting properties of muscle proteins and perhaps impeded by enclosed air. Denaturation of protein and migration of fat make the internal structures of meat less hydrophilic and so may also delay rehydration.

At a Food Service and Technology Symposium in Sydney in 1973, it was stated that the catering industry has a need for more and better instant foods; it is not interested in dehydrated foods unless they can truly be called 'instants', i.e. they must be capable of immediate rehydration. Rapid reconstitution is therefore one of the most important virtues of freeze-dried foods.

One procedure tried in the CSIRO Food Research Laboratory to speed up rehydration is the use of a proteolytic enzyme (Mellor and Irving 1970). Oysters freeze-dry well but are notably difficult to rehydrate. In our trials we found that freeze-dried whole oysters could be reconstituted in about 15 minutes in a warm water solution of Pronase, a proteolytic enzyme of bacterial origin. Presumably the enzyme attacks some of the bonds formed during freeze-drying and thus permits the entry and sorption of water.

Freeze-dried beef and pork may be reconstituted more quickly in the presence of EDTA and phosphate, which have the property of chelating magnesium and calcium ions (Wismer-Pedersen 1965). These ions are presumed to take part in salt bridges formed between the fibrillar proteins, but when the ions are bound by chelation the muscle retains a less rigid structure and sites are available for the sorption of water.

Irreversible reactions

As well as the changes already mentioned, there are other irreversible reactions that may occur during freeze-drying, and particularly during storage of freeze-dried foods.

Oxidative reactions

Freeze-dried foods are especially subject to detrimental oxidation because their large internal surface areas and low moisture contents permit ready access of atmospheric oxygen to components sensitive to oxidation.

Lipid constituents, notably unsaturated lipids, are subject to oxidative rancidity. Studies in model systems, and also in foods such as freeze-dried salmon, indicate that lipid oxidation is favoured at low moisture contents or, conversely, the presence of some water inhibits lipid oxidation. This inhibitory effect appears to be due to two mechanisms: metal ions such as cobalt which catalyse lipid oxidation are deactivated by hydration; and also water forms hydrogen bonds with hydroperoxides, the primary products of oxidation, and breaks reaction chains. So freeze-dried foods, such as pork, chicken, dairy foods and salmon, are reported to show greater stability of flavour and colour at moisture contents of 3–3·5% than at lower values.

Pigments are another group of food constituents that are subject to oxidative deterioration. The carotenoid pigments, such as carotenes and lycopene in fruits and vegetables and astacene in shrimps, prawns and salmon, may suffer oxidative bleaching. The muscle pigment, myoglobin, in flesh foods may be oxidized to metmyoglobin.

Proteins are also subject to oxidative denaturation by formation of disulphide bonds from sulphydryl groups.

These observations all indicate that exclusion of oxygen is desirable in the packaging and storage of freeze-dried foods, and indeed is essential for some foods. The need to remove and exclude oxygen makes great demands on packaging techniques and package properties, and the use of in-package scavengers of oxygen has been widely investigated.

Browning reactions

In the absence of oxygen, the most important deteriorative reaction in freeze-dried foods is the Maillard reaction between carbonyl groups and amino groups, the reaction also known as non-enzymic browning. Products of this reaction contribute to darkening, loss of palatability, loss of solubility of proteins and loss of nutrients such as lysine and ascorbic acid. The rates of browning reactions increase with increasing temperature in drying or storage. The Arrhenius activation energy for browning reactions is of the order of 130 kilojoules per mole whereas a typical activation energy for water removal is about 40 kilojoules per mole; therefore for a given amount of water removed, the lower the drying temperature, the less is the extent of browning. It follows that the conditions of freeze-drying are favourable to minimize browning reactions.

The effect of moisture content is such that many foods show highest rates of browning at intermediate moisture contents (water activity about 0·4). Here also there are advantages in freeze-drying because as the ice front recedes by sublimation each region of the drying food tends to pass rapidly from a high to a low moisture content.

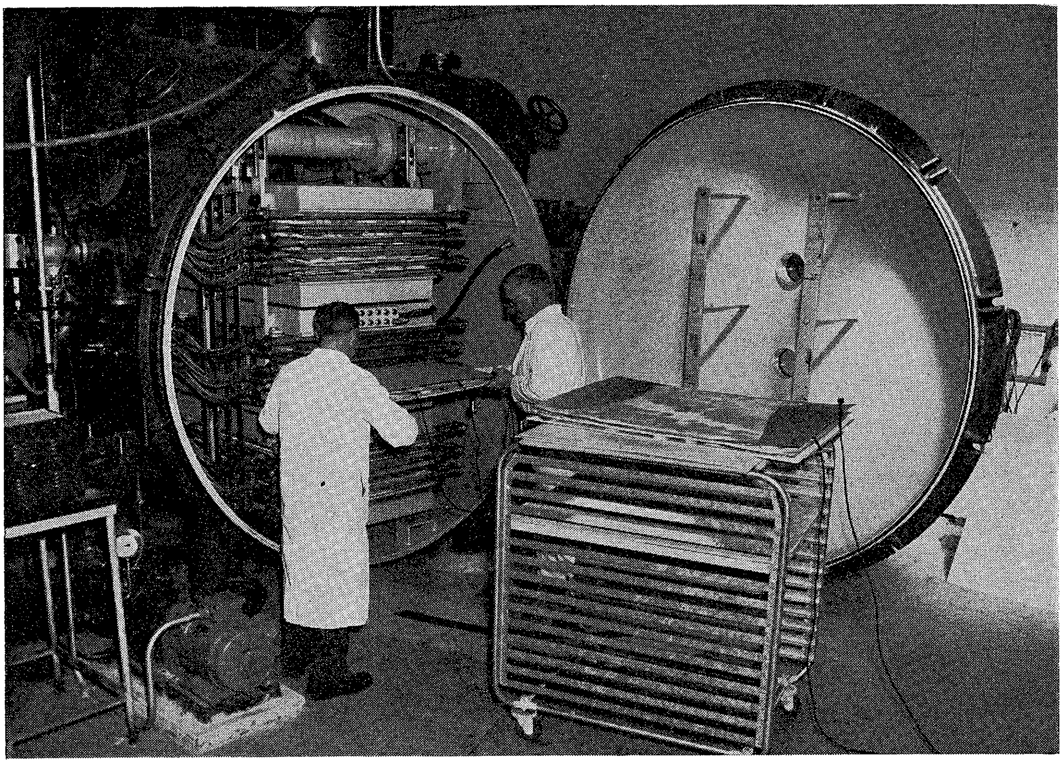
In drying fruits and vegetables by ordinary air-drying procedures it is common practice to control browning reactions by the use of sulphur dioxide. This is also possible in freeze-drying, and studies in the CSIRO Food Research Laboratory have shown some benefits in giving peas a sulphite dip before freeze-drying (Mellor and Irving 1970).

Loss of volatiles

At first thought it might be expected that volatile aroma constituents would be lost readily during the freeze-drying of foods under high vacuum. Many of the alcohols, aldehydes, esters and other organic compounds that contribute aroma to foods have a lower boiling point and a higher volatility than water, and would be expected to evaporate at least as readily as water. Fortunately, however, the retention of volatiles during freeze-drying is much better than would be expected on this superficial view.

There have been many basic studies of this phenomenon in an endeavour to find a satisfying physical explanation. High retention of volatiles is observed not only in freeze-drying, but also in drying from the unfrozen state. However, the phenomenon has been especially studied during the freeze-drying of model systems, some with natural substrates such as apple slices, others with systems such as pectin gels, solutions of low- or high-molecular-weight sugars or oligosaccharides such as malto-dextrin, starch and cellulose, and non-carbohydrate systems such as polyvinylpyrrolidone, a polar polymer analogous to proteins. To these systems have been added test volatiles such as acetone, alcohols and esters, and the retention of these volatiles during freeze-drying has been followed by gas chromatography or radioactive labelling.

In the experimental studies the kind of observations that are made are these: during the early stages of drying, water and volatiles evaporate together as would be expected, but when the water content drops to a certain level or, putting it the other way, when the soluble solids content reaches a certain level, loss of volatiles ceases, even though loss of water continues. If the system is rehumidified above the critical water content, evaporation of volatiles commences again. At the conclusion of drying, a similar pattern of retention is observed for compounds differing greatly in volatility. Prolonged exposure of the dry solids to mild heat and vacuum does not cause any further loss of volatiles. The actual retention of volatiles observed may exceed 90%, although it may often be much lower.



Loading a commercial freeze-drier. (Photo courtesy Ministry of Agriculture, Fisheries and Food, Britain.)

Several theories have been put forward to explain the observations. Early theories assumed that volatiles were adsorbed on sites in the dry matrix, but in fact the adsorption isotherms of organic volatiles on dry carbohydrates do not suggest that they are more strongly adsorbed than water. In cellulose model systems, however, reabsorption of volatiles in the dry layer has been demonstrated (Chirife and Karel 1973).

Another theory envisaged the formation of a surface skin which was impermeable to volatiles. This theory has been rejected because retention of volatiles is uniform throughout the freeze-dried mass; there is no further loss of volatiles when the surface layer is scraped off, and there is no loss when the dried mass is ground and subjected to vacuum.

The Dutch worker Thijssen and his colleagues have put forward a theory that gives good predictions of observed behaviour.

The basis of this theory is that the removal of water and volatiles is governed not by relative rates of evaporation but by rates of diffusion; as the solids content increases during drying, the diffusion coefficients of both water and volatiles decrease, but those for volatiles decrease much more steeply than for water. The practical effect is that at low water contents the system becomes virtually impermeable to organic volatiles.

American workers, Karel and colleagues at the Massachusetts Institute of Technology, have also put forward a theory which is not necessarily in conflict with that of the Dutch scientists but tries to provide a picture of the physical state of the system. This picture begins at the freezing stage. When water in a food is frozen as crystals of ice there remain between the crystals pools of concentrated solutions of various food constituents including volatile flavours. The observation that slow freezing rates favour retention of volatiles more than fast freezing rates is attributed to the fact that slow freezing allows more time for diffusion of solutes from the freezing front and therefore more complete segregation of solutes and volatiles in the concentrated pools.

When drying commences, water and volatiles evaporate together, as has already been stated, down to a certain water content, at which point ice is assumed to have disappeared. In the partly dried solids, the Dutch workers maintain that diffusion of water is possible, but diffusion of organic volatiles is entirely impeded. The American workers explain in molecular terms that hydrogen bonds between carbohydrate hydroxyls and water are replaced by hydrogen bonds between the carbohydrate molecules themselves, forming an amorphous glassy solid in which the volatiles are sealed in micro-regions. Microscopic examination of freeze-dried solids has demonstrated the presence of these micro-regions. The system in which flavour volatiles are protected in a matrix of amorphous carbohydrate is analogous to 'locked-in' flavour preparations that are offered by the flavour industry. The fact that the matrix must be amorphous rather than crystalline was demonstrated in a lactose model system containing propanol, where the propanol was lost when the lactose was allowed to crystallize. In starch and to a less extent in cellulose systems, entrapment of volatiles within hydrogen-bonded polymer chains is considered to be the dominant mechanism of retention (Chirife and Karel 1973).

When freeze-dried systems are rehumidified a reverse change of events is proposed. The carbohydrate matrix is disrupted by adsorbed water so that at a specific relative humidity entrapped volatiles are able to evaporate.

Conclusion

To summarize the effects of the freeze-drying process on the product, we may say that freeze-dried foods show better retention of structure, they rehydrate more readily and quickly, and they retain natural aromas, flavouring, colours and nutrients better than foods dried by other techniques.

On a world basis, freeze-drying is being used mainly for preparing instant coffee and tea where retention of aroma and rapid reconstitution are the paramount requirements for high quality. In our own experience in the CSIRO Food Research Laboratory, excellent results obtained in freeze-drying mushrooms, for instance, and yoghurt, prove the value of the process when retention of structure and aroma is important.

Freeze-drying finds a significant place in food technology when it is applied to foods that require its unique advantages to retain acceptable quality in the dried product.

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Mechanizing cheesemaking

By J. Czulak

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A review of progress in the last 25 years

Cheesemaking is an old art. It has been practised for several thousand years by peoples of the Eastern Mediterranean and European civilizations. The simple art became modified in different regions, giving rise to many hundreds of varieties of cheese.

At the beginning of this century cheese attracted the attention of analytical chemists and bacteriologists whose aim was to unravel its composition, bacteriological flora and enzymatic activity. But the method of manufacture remained virtually unaltered until about the 1950s when technologists and food engineers began to develop schemes for the mechanization and automation of cheesemaking.

The cheesemaking process

Before outlining any of these schemes I must emphasize that the process of cheesemaking is complicated, comprising many different steps or unit operations. A few of the operations are common to all types of cheese, but many are different for each type. It will therefore be easier if first of all I group the steps or unit operations in the cheesemaking process according to the types of cheese that are produced by following one set of operations or another (Fig. 1). Then I shall go on to describe the machines that have been designed to take over some of these operations and that can therefore be used for making a particular type of cheese. Readers who would like more information will find a fuller description of the cheesemaking process and cheesemaking machines, and a full bibliography, in the Centenary Book of the Christian Hansen Laboratorium (Czulak 1974).

Traditionally, all types of cheese have been made by the batch-handling method; recently one or two continuous methods have been tried, but these are still the exception rather than the rule. I will deal with the continuous methods separately, later in the article.

Steps for making various types of cheese

In all methods of cheesemaking the first operation is the same: it consists of coagulating the warm milk by the addition of rennin or some other coagulating enzyme, and then cutting the coagulated curd. This can be called Step 1.

I shall now describe the set of steps or unit operations that are followed in making some of the more popular types of cheese.

Type 1

These are the soft cheeses, including Brie and Camembert. The method of making them is comparatively simple, employing only two further steps after the curd has coagulated and has been cut or broken into smaller volumes.

Step 2. The slurry of curds and whey is transferred to a perforated container or a hoop without a bottom and this rests on a screen, thus permitting the whey to drain while the curd consolidates. After a time the container is inverted to enable the curd to consolidate uniformly.

Step 3. The curd is removed and drained again, and then sprinkled with dry salt.

Type 2

These are the semi-hard cheeses such as Edam, Gouda, Danbo and Port du Salut. After Step 1, the following additional steps are required in their manufacture:

Step 2. The particles of curd contract or shrink as a result of the action of the rennin and of raising the temperature of the curd

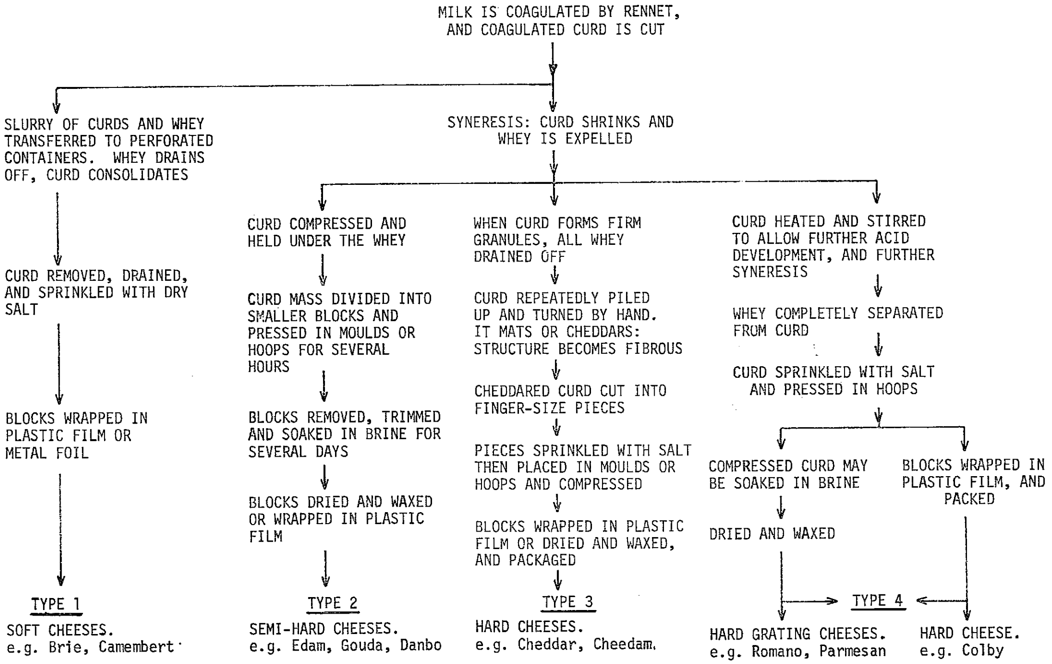

Fig. 1. Steps in making the four main types of cheese.

('cooking' it), while it is kept agitated. This shrinkage of the curd and loss of whey from it is called syneresis; with minor variations it is carried out in making almost all types of cheese.

Step 3. The curd is compressed into one mass and held under the remainder of the whey so as to exclude the air from it.

Step 4. The curd mass is divided into smaller blocks and pressed in moulds or hoops which are lined with cheesecloth or other material suitable for draining the whey. It is pressed for several hours at least.

Step 5. The blocks of curd are removed, trimmed, and then salted by soaking in brine for several days.

Type 3

These are the hard cheeses; they include Cheddar, Cheedam, Cheshire and Gloucester, of which Cheddar is the main variety on the Australian market.

After Steps 1 and 2 (syneresis), the following steps are followed:

Step 3. When the curd is sufficiently firm to give relatively 'dry' curd granules, all of the whey is drained from it.

Step 4. With the help of force of gravity the curd granules are compressed into one mass by piling up the curd and turning it by hand at intervals to cause it to deform or flow under its own weight and thus develop a fibrous structure; this step is called cheddaring.

Step 5. The matted or cheddared curd is cut, milled or shredded into pieces about the size of a finger.

Step 6. The small pieces of curd are sprinkled with dry salt, and after a short interval are placed in moulds or hoops and then compressed.

Type 4

This type includes the hard cheeses such as Colby, and the very hard or grating varieties such as Parmesan and Romano.

Step 2. For this type of cheese, after Step 1, the curd is brought to a high temperature and stirred in order to expel more whey and to bring about a more complete syneresis.

Step 3. The whey is then completely separated from the curd.

Step 4. The curd is sprinkled with dry salt and is pressed in hoops.

Step 5. After being compressed in moulds or hoops the curd is further salted by

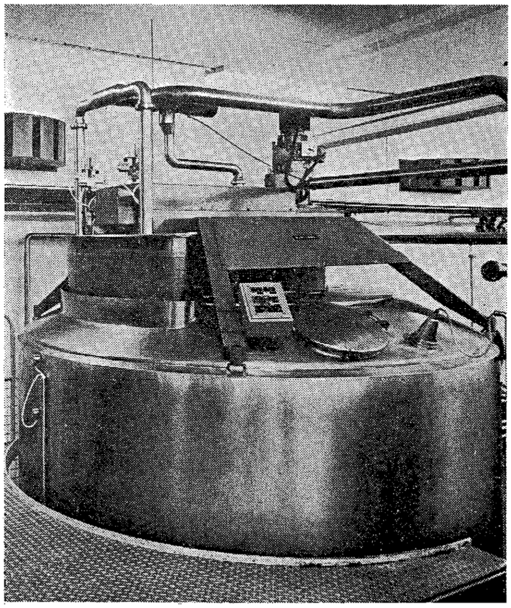

Fig. 2(*a*). Alfa Laval Ost Tank.

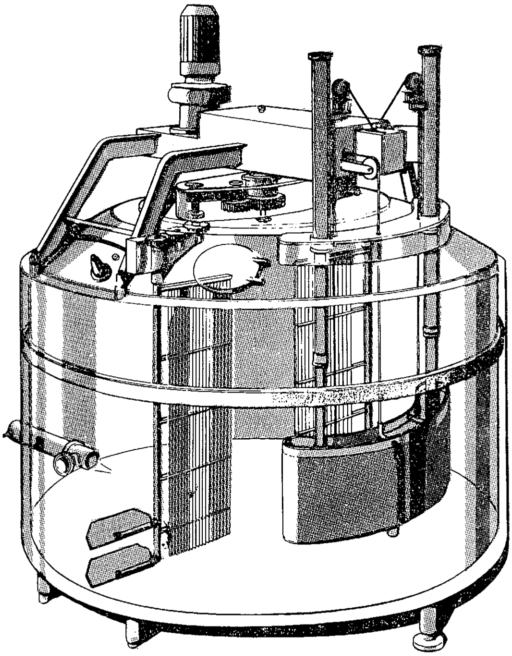

Fig. 2(*b*). Diagrammatic representation of Fig. 2(a).

immersion in brine.

Note that with cheeses of this type there is no cheddaring.

Making cheese by hand

Throughout history all cheeses of every type were made manually, with wooden vats or primitive copper kettles and simple wooden implements to break the coagulated curd and stir it. Gradually, tinned or stainless steel vats replaced the earlier wooden or copper ones. Then came the first inventions. These performed one single function only: for instance, a crude manually operated stirrer might be replaced by a mechanically or electrically driven agitator. It was by means of such single-function devices that cheesemaking attained partial mechanization in the years before the late 1940s, when mechanized systems, embracing many steps in the cheesemaking process, began to emerge.

Within the first half of the twentieth century methods of manufacture of various dairy products other than cheese became fully mechanized and were even automated to a substantial degree. What held back a similar development in the manufacture of cheese was the number and the complexity of steps in the method, and the fact that different types of cheese used a different group of steps or operations, or used them in a different sequence. Within the general types of cheese such as soft, semi-hard, etc., there were many varieties, each of which also varied the cheesemaking process to some extent. The diversity made mechanization very difficult.

Nevertheless, from the early fifties on, research workers and engineers in various parts of the world began to investigate the cheesemaking process with the aim of mechanizing it. Now, some 15 or 20 years later, as a result of that research a considerable number of mechanized and partly automated systems have been developed for the manufacture of most of the better-known and economically significant cheese varieties.

We shall now look at some of the more important mechanical systems already in commercial operation.

Mechanical and/or automatic systems for cheesemaking

Automating Step 1 (all Types)

Cylindrical or oval vats with automatic controls have been introduced suitable for carrying out the first operation in making all types of cheese. The vats are usually jacketed vessels equipped with rotary knives or agitators which are mounted on a central or off-centre shaft. The milk is held in these vats until it coagulates and is then cut by means of the rotating knives into particles of the desired size. Usually the curd is held in the vats after cutting, with the temperature at the correct level to bring about the desired degree of syneresis. The slurry of curds and whey is then discharged, usually by gravity, into other vessels.

Since the step of coagulating and cutting the curd is common to all types of cheese, these vats can be adapted to carry out the first operation in practically any of the mechanized cheesemaking systems at present in operation. A type of vat called an Ost Tank (Alfa Laval) is shown in Figure 2.

Mechanizing Steps 3 and 4 (Type 2)

The steps of compressing the curd in the whey, then draining the whey and dividing the curd into slabs for hooping, are common to some of the soft cheeses of Type 1 and to most of the semi-hard cheeses of Type 2. Equipment has been developed for carrying out these operations.

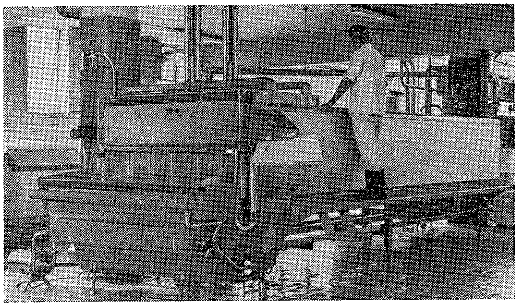

Fig. 3. Tebel Strainer Vat, type D.B.S.

On completion of syneresis in the vat the mixture of curds and whey is emptied by gravity into a rectangular vat; above the bottom of this is fitted a perforated belt. The wall at one end of the vat can be made to slide up and down, and at this end the vat is fitted with a guillotine and other knives to cut into slabs ready for hooping the fused curd which is moving along the perforated belt. A vat of this type is shown in Figure 3.

Automating Step 4 (Type 3)

Machines have been developed for the important operation of cheddaring, which is common to all varieties of cheese in Type 3.

After syneresis has been completed the free whey is separated from the curd, usually by pumping the slurry onto a stationary perforated screen or else onto a slowly moving conveyor belt. These screening devices, which drain off the whey, form the first stage of the cheddaring or curd-fusing machine.

There are three main cheddaring machines available at present, all designed to fuse the curd and deform it into a partly fibrous mass. The operation of all three machines is fully automated. The first sort of machine is best represented by the Bell-Siro Cheesemaker 2, Mk III, shown in Figure 4. In this machine the drained curd is fused in open buckets linked to form an endless chain; pressure is applied to the curd mechanically to assist in its deformation. At the end of its travel along the chain the cheddared curd is discharged from one bucket after another to be milled before it is salted.

A second sort of cheddaring machine works in the following way: the curd is first separated from the whey on a screen or a perforated belt, and is then fed continuously to the top of a vertical tower. As the curd falls from the top of the tower it fuses and deforms under its own weight and emerges from the bottom of the tower as a fibrous mass ready for milling.

In a third sort of cheddaring machine the curd after screening is compressed and deformed between endless belts travelling in the same direction until it is ready for discharge into a mill.

There are other types all embodying the same principles: all pass the curd over a screen to drain off the whey and then fuse it by pressure and deformation. However, none of the other cheddaring machines has as yet found wide commercial application.

Mechanizing other steps in making Type 3

After the curd has been cheddared it needs to be milled, salted and hooped. Several types of machine have been introduced to carry out these operations on a commercial scale. They usually consist of a mill, an elevator to carry the cut curd to the top of the salting machine, a device for

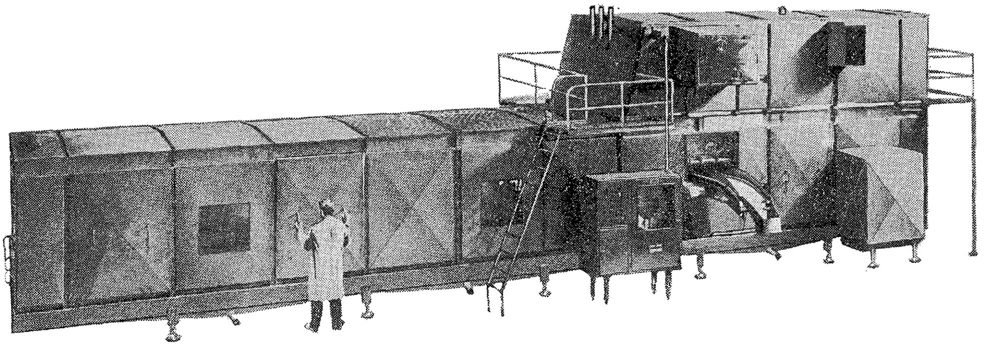

Fig. 4(*a*). Bell-Siro Cheesemaker 2, Mark III.

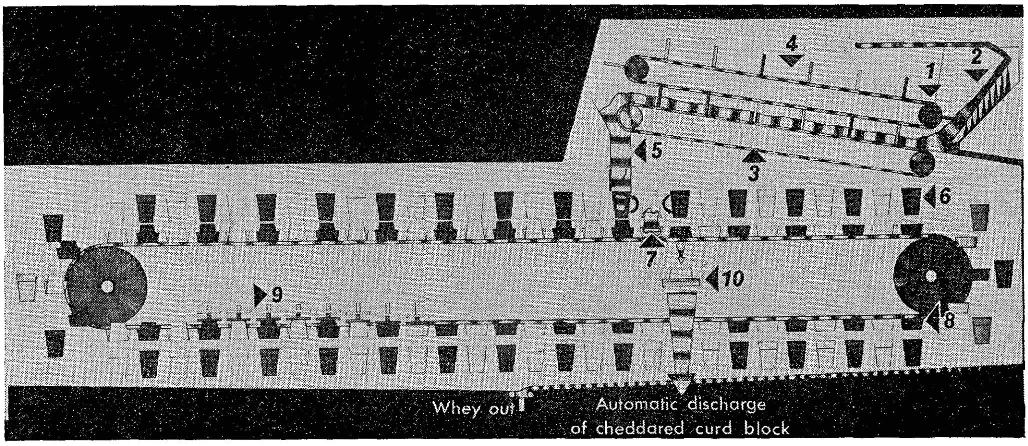

Fig. 4(*b*). Diagrammatic representation of 4(a). 1, Oscillation nozzle; 2, stationary curd and whey separation screen; 3, de-wheying and dry stirring conveyor; 4, continuous curd stirring rakes; 5, curd weighing hopper; 6, first stage cheddaring buckets; 7, curd bucket invertor; 8, second stage cheddaring buckets; 9, curd compression unit; 10, curd discharge conveyor.

apportioning the salt, a device for weighing the curd, and a hoop conveyor. An example of such a machine, the Bell–Siro Cheesemaker 3, is shown in Figure 5.

It may be noted here that manufacture of cheeses of the very hard type (Type 4) has not reached any significant degree of mechanization.

Mechanizing the last step (all Types)

None of the machinery described so far is meant to carry out the final operation that transforms the loose curd into a cohesive mass of the desired shape, ready for maturing into a cheese.

In practice, nowadays this last step is accomplished by compressing the curd in telescopic hoops or moulds in mechanically, hydraulically or pneumatically operated presses which may be horizontal or vertical. The hoops are usually held under pressure for several hours.

When the pressing is finished the curd, now in the shape of the cheese to be, is taken out of the hoops or moulds. It is then wrapped or waxed, either by hand or by automated machines, before being transferred to a temperature-controlled room for storing until it reaches maturity.

Continuous methods

As we have seen, the process for making virtually every variety of cheese incorporates the coagulation of milk by rennet or by enzymes acting in a similar way. Coagulation is not instantaneous: it requires some time to take place. This is why it is not easy to convert the batch process normally used in cheesemaking into a continuous process that will be economically sound.

Nevertheless, attempts have been made in that direction. The first of these attempts was made after biochemical research revealed that the coagulation of milk by rennet is a two-stage reaction. The first stage, during which the rennin-sensitive phenylalanyl–methionyl bond is cleaved, can take place at a relatively low temperature. Once this reaction is completed the second stage, coagulation, which requires a higher temperature, can be accomplished almost instantaneously when the milk is warmed to the necessary temperature.

A practical process based on this principle makes use of holding tanks in which milk that has been seeded with rennet to ripen it is held for several hours to complete the first stage. The milk is then heated by the addition of hot water or by passing through a warm vessel in order to coagulate it. From this point on the process is continuous and thus equipment of much smaller capacity is required to deal with the same volume of milk.

Attractive as such processes are, they have not yet been adopted for large-scale commercial manufacture of cheese. The same applies to a semi-continuous process evolved to the pilot stage by the author and one of his colleagues. In this process, Step 1—the first operation in cheesemaking—is split into three stages each of about 45 minutes' duration. Coagulation, cutting and 'cooking' (syneresis) are effected one after another in separate enclosed vats arranged one above the other, 'cascade' fashion.

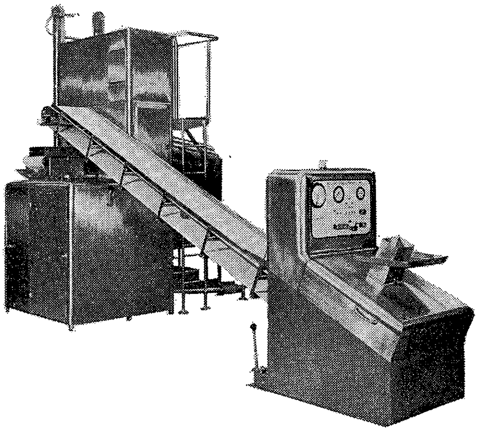

Fig. 5. Bell-Siro Cheesemaker 3.

A novel continuous process which shows great promise has been evolved in France. In this process, now approaching commercial application, the milk is concentrated by ultrafiltration and thereafter coagulated and processed continuously.

Is machine-made cheese just as good?

It has often been claimed by cheesemakers that cheese of high quality could not be made by mechanical methods and that to make excellent cheese some special art is required. On the contrary, however, practical experience so far has not substantiated such claims. Cheese of excellent quality has been produced by mechanized and even automated manufacturing methods. It has been observed, too, that cheese produced by such methods is often more uniform in quality.

Moreover, it has been found in commercial practice that mechanized manufacture is often more economical not only because it saves labour but also because the wastage of curd is less and thus the yield of cheese is significantly higher.

Reference

Czulak, J. (1974). 'Mechanization and automation of cheese manufacture—a synoptic view', in the Centenary Book of the Christian Hansen Laboratorium S/A, Copenhagen.

Further reading

A.P.R.I.A. (1971). Association pour la Promotion Industrie–Agriculture. Les nouveaux procédés mécanisés et continus dans l'industrie alimentaire. Tome 1: Fromagerie. (A.P.R.I.A.: Paris.)

Improving quality in fresh tomatoes

Dr W. B. McGlasson returned to FRL recently after 11 months at Purdue University, Indiana, U.S.A., where he worked on aspects of the quality of 'green wrap' tomatoes. Green wrap tomatoes are fully grown fruit which are picked at the green stage to permit shipment to distant markets.

As there are no satisfactory non-destructive indices of maturity to guide growers in harvesting tomatoes, commercial shipments generally include some tomatoes picked at very immature stages. Very immature fruit cannot develop high quality, even when held under conditions ideal for ripening. Moreover, treatment of immature tomatoes with ethylene, which is used successfully to ripen bananas and other fruits, does not here result in uniform ripening. At present, commercial shipments of tomatoes often require repeated sortings to provide batches of fruit at a uniform stage of ripeness for retailing, with a consequent increase in handling costs.

Dr McGlasson's work on tomatoes at Purdue University aimed at discovering the nature of the processes that initiate ripening. It may be possible to develop specific methods for controlling the onset of ripening; ideally, these methods might be suitable for pre-harvest application. Associate Professor E. C. Tigchelaar is developing strains of tomato mutants isogenic with the well-known Rutgers cultivar, to enable the study of the genetic and biochemical control of several parameters of fruit quality. Two of the mutant strains under development are *rin* and *nor*, both of which produce fruits that grow normally but fail to ripen and colour. Mature fruits of the mutants remain sound for many weeks at ordinary room temperatures. These strains probably have little commercial value in themselves, but they are useful for studying ripening in normal fruit since their inability to ripen is considered to be due to a simple genetic change.

The physiology of *rin* and *nor* has been intensively studied and it seems that fruits of these mutants lack what may be called the 'biochemical apparatus' for normal ripening. Studies have now begun at Purdue aimed at detecting the expected differences in proteins between fruits of mutants and of normal strains. Dr McGlasson proposes to continue at FRL physiological and biochemical studies that will be linked with the investigations at Purdue University.

The concern felt in the U.S.A. about the uneven quality of green wrap tomatoes contributed to the recent formation of a Tomato Quality Workshop, which held its first meeting in Florida in February 1974. The Workshop brought together investigators from many U.S. universities and from laboratories of the United States Department of Agriculture (USDA). Among the topics discussed were genetic control of quality, conditions of cultivation, post-harvest handling and the nutritional composition of tomatoes.

Much work is being done in the U.S.A. which could quickly lead to significant improvements in the quality of fresh tomatoes. Since one of the major reasons for poor quality is the harvesting of very immature fruit, there is considerable interest in devising non-destructive methods for mechanically sorting fruit according to maturity. One promising method being investigated by the USDA at the Agricultural Marketing Research Institute, Beltsville, employs light transmission equipment to detect internal changes in pigments. Of course, such an approach does not overcome the basic difficulty of preventing the picking of immature fruit, and hence research on this problem is of great importance.

Specialist courses for the food industry

Several short courses were organized by MRL recently: two schools for the meat industry, one for engineers and the other for people in management, were run consecutively in Perth during March; the second school was repeated in Darwin. Instructors were Messrs A. Graham and J. C. Bensink from Cannon Hill and Mr D. W. Roberts, MRL's Extension Officer in Perth.

A two-day school on vacuum packaging of chilled beef was run at MRL early in April and repeated in Sydney in May. Lectures were given by Mr L. E. Brownlie (Australian Meat Board), Mr M. F. Coffey (Overseas Containers Ltd), and Dr W. R. Shorthose, Mr J. C. Bensink and Mr B. Y. Johnson, all of MRL.

An 'Apple utilization workshop', to be designated No. 7 in the series of Specialist Courses for the Food Industry, will be held at Hawkesbury Agricultural College, Richmond, N.S.W., on 4–6 September 1974; it is a joint venture with the College and the Food Engineering Group of the AIFST. Details are available from the Technical Secretary, FRL.

Terence James Riley, 1922-74

Terry Riley died in hospital on 10 March 1974; he had been in failing health for some time.

Terry joined the Division when it was at Homebush as an Assistant, in May 1949, and was a Senior Technical Officer at the time of his retirement, on medical grounds, in October 1973. During the whole of this period he was an important member of the small group working on post-harvest preservation and storage of fresh fruit. He had a key role in the conduct of many important research projects such as control of apple scald, C.A. storage of apples and pears and effects of orchard factors on the storage life of apples.

Terry took an active interest in social affairs in the Division and will particularly be remembered as the Father Christmas at many children's Christmas parties and as a foundation member of the Bridge Club. He was liked by everybody, and we are saddened by his untimely passing.

E.G. Hall

News from the Division

Appointments

Dr Brian D. Patterson has returned to the Plant Physiology Unit at FRL, North Ryde, to work on the effects of chilling injury in plants. Dr Patterson spent the past two and a half years at East Malling Research Station, Kent, England, where he worked on the biochemistry of apple storage, particularly the effect of controlled-atmosphere conditions on subsequent changes in ripening behaviour.

Miss Betty Baker, B.A., A.L.A.A., has joined the staff of FRL as a librarian; she was formerly in charge of the library of the Public Transport Commission of New South Wales. Miss Baker spent some weeks of 1973 studying libraries in the U.S.A.

Transfer

Dr J. R. Yates has relinquished his position as leader of the Industry Section at MRL to transfer to CSIRO Head Office in Canberra as Assistant Secretary (Industrial and Physical Sciences).

Visiting worker

Dr B. Ribadeau-Dumas of the Station Centrale de Recherches Laitières, Jouy-en-Josas, France, spent six weeks late in 1973 working at DRL. He is the leader of a team of protein chemists who recently determined the amino-acid sequences of the main caseins of cow's milk. His particular interest during his visit to Australia was a study of the caseins of Australian monotremes and marsupials.

Award

E. J. McMurchie of the PPU, who obtained a first-class honours degree from Macquarie University in 1973, has won a three-year Commonwealth Post-Graduate Award to work for a Ph.D. in the Biochemistry Department at the University of Adelaide.

Work overseas

Early in January Mr L.L. Muller of DRL paid a brief visit to Ireland at the invitation of the Irish Dairy Board for discussions on research and development in areas of mutual interest, including whey utilization. His visit reciprocated one to Australia last year by Mr Fergus Kelly, Development Manager of the Irish Dairy Board.

General

Mr M.V. Tracey, Chief of the Division, has been elected Titular Member of the Food Section of IUPAC (International Union of Pure and Applied Chemistry) for the period 1973–77. IUPAC is particularly interested in studying matters that are of international importance to pure and applied chemistry and that need regulation, standardization or codification.