1. IMPORTANT PROBLEMS IN FOOD PROCESSING

1.1 Introduction

Food processing includes all the activities that control the nature of food between the agricultural and marine production and its final eating by the consumers. It includes everything from the controlled conditions in the transport and storage of whole fresh meat, fish, fruit and vegetables, to the complex processing producing food ingredients followed by manufacturing to produce the final consumer product. Before being eaten, biological materials from agriculture or fishing are transformed through processing into the finished foods the consumer wants. Food processing makes the food products more attractive, more satisfying, safer and easier to eat, and preserves them from deterioration. It includes building up desirable constituents and removing or reducing undesirable ones, encouraging enzymes to develop desirable flavours and textures and removing or inhibiting enzymes causing undesirable changes, growing microorganisms to create flavour and texture and destroying them to prevent harm to the consumer or decay of the food.

Food products are the outcomes of food processing, and it is important to identify the desirable product qualities and the undesirable and even unsafe product qualities. The products are the aim of food processing, and processing needs to be designed and controlled to give the product qualities identified and wanted by the consumers. Food processing is diverse, complex, and often carried out on a large industrial scale.

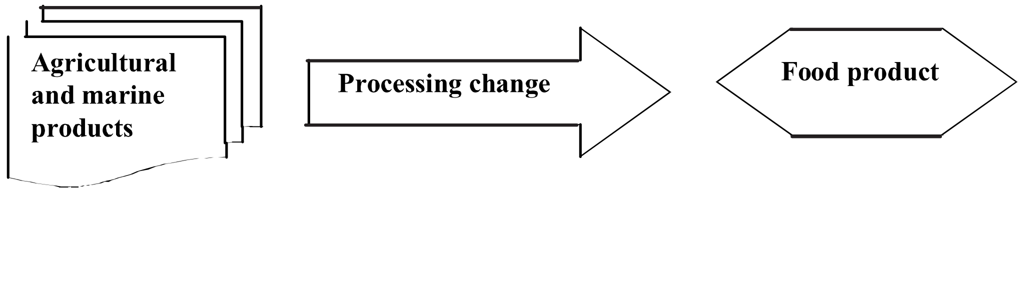

Figure 1.1. Conversion in food processing

1.2 Changes During Food Processing

Processing causes changes in the food materials; some of the changes are shown in Table 1.I.

TABLE 1.I
Changes in food materials during processing

Chemical:	hydrolysis, oxidation, polymerisation, denaturation, de-amination, browning, hydrogenation, esterification, destruction of toxic substances.
Physical:	gelation, hardening, softening, toughening, emulsifying, colour loss/gain.
Biological:	growth and death of microorganisms, glycolysis, physiological changes in ripening.
Nutritional:	constituent availability, protein changes, loss of vitamins, amino acids loss, destruction of anti-nutritional substances.
Sensory:	aroma and flavour loss, aroma and flavour changes, texture changes, colour bleaching and darkening.

From Earle & Earle (1)

These changes can be measured, so their progress during processing can be followed and studied by the food technologist. The progress of processing can be measured in many ways, such as chemical analysis, physical measurements, counts of microorganisms, and colour, texture and flavour assessments by sensory panels. Changes can often be described in terms of the changing chemical composition, that is changes in the concentrations of the chemical components, but sometimes this is not possible and sensory, physical or microbiological measurements are used to quantify the changes.

Measurement reveals continuing change with time during the process. As our knowledge extends over ever-wider ranges of foods and food processing, and our analytical skills increase, the measured changes are increasingly found to be systematic and describable in quantitative terms. The quantitative data from change measurement can be fitted to mathematical equations and to physical models. The models can be tested and, if necessary, modified until they fit observations adequately for practical processing purposes. Once the models are sufficiently established, they can be used to predict changes in processing between and sometimes beyond the original processing conditions. The models can be employed industrially to guide the processing, to control its extent, and to design new processes and equipment. They can predict outcomes under different processing conditions, conditions that can be set before the processing is started and regulated until completion. Important processing variables include temperature, time, moisture level, pH and atmosphere, and different levels can be set to give the processing conditions.

The changes start when the process begins, and move on through the processing towards defined ends. The changes differ in their desirability between what are called customarily food processing and food preservation. Food processing, as seen traditionally, is about causing wanted changes in the food as it moves towards a finished product. These changes improve the food, adding to its value. For economic reasons, they often need to happen speedily. Food preservation aims to slow down undesirable changes, and conditions have to be organised so that the changes happen as little as possible. They are deleterious to the quality and value of the food. The changes are normally spontaneous, arising from the instability of the food, and the processing conditions are arranged to slow them down. Since they are both about change, its manipulation and its control, and since they can both be technologically described in the same way, it is convenient to think of the whole area as that of dynamic food processing.

In all dynamic food processing, the aim is always towards a defined product outcome. In food processing, the defined end is an optimum food product. In food preservation, the defined end is a point at which the food becomes significantly less edible or desirable, reaching a minimum acceptable quality. This is the point at which quality is measurably degraded and which the preservation process is designed to avoid reaching. Both involve changes that the technologist seeks to understand and keep under control. The changes take place under the scientific laws that govern reactions. They are influenced both by material qualities and by processing conditions, many of which are, or can be brought under the control of the processor. This book looks at the ways in which these changes occur, at quantitative descriptions of them in simple terms that can be used in practice, and at examples of industrial application.

Think break

Select two food-processing operations with which you are familiar.

* Identify all the changes that take place in the raw materials as they are moved through processing towards finished foods.
* Identify the individual chemical constituents so far as you can and the changes in these that occur.
* Consider the ways in which the changes are regulated and under control from the beginning to the end point in each stage of the process.

As an introduction, a number of important challenges involving the dynamics of change in food processing have been selected and will be outlined. Specific examples illustrate these challenges, focusing on food products and on food processing. They will show how, in particular industrial situations, the challenges have been studied using the methods of process reaction technology. In the later chapters there is more detailed discussion of how these methods can be applied generally and specifically to a range of food processes.

1.3 Food Products

Food products cover all edible products in the food system: industrial, foodservice and consumer products, primary produce, food ingredients, retail foods, and domestic foods. At the end, consumers determine the qualities expected of these products, but intermediate customers in the food system, such as food processors, food manufacturers and food retailers, very often set the working product specifications. Although these products may differ a great deal, their basic qualities can be grouped into composition, nutritional value, sensory, safety and health. In studying food processing, it is important firstly to identify the specific critical and important food qualities, called *product attributes* (or characteristics), required in each product, then to set the optimum values of the product attributes, so that food processing can be designed and controlled to attain the specified values for these specific attributes.

1.3.1 Consumer expectations

Consumer product expectations are built up from eating, or from publicity in the case of new and untried products. Consumer concerns include nutrition, food safety, shelf-life, as well as social and environmental aspects (2), but customers also very much want desirable sensory qualities and psychological benefits in the food. Expectations are becoming more specific all the time as consumers' knowledge of food qualities increases. They want specific qualities and they want them to be true for all units of the products. For example, in the supermarkets, the customer wants today's product to be true to the type and the quality bought last week or last month, and to a high degree of precision unless good reasons are produced for any change and such changes are acceptable.

Consumer expectations translate directly into buying specifications. When these product quality demands are combined with formal consumer requirements to list compositions and nutritional contents on packets, the food manufacturer has to pay attention, often minutely, to processing changes and to bring them under very precise control. The only real way to do this efficiently is to seek detail of, and manipulate, the process conditions as carefully as is currently possible.

1.3.2 Product attributes

A food product can be viewed at three levels – the consumer's product concept, the total company product, and the company's basic functional product (2). In setting the product aims for food processing, the consumer's product expectations have to be converted into the company's basic functional product, which is described by its physical, chemical, microbiological, sensory and nutritional attributes, as shown in Fig. 1.2.

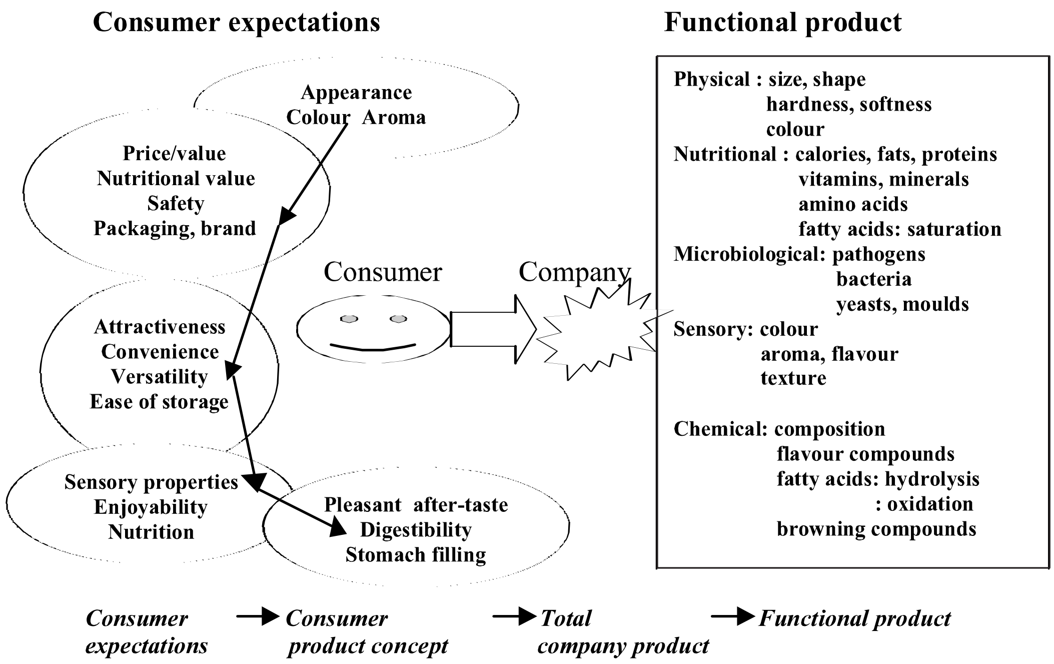

Fig. 1.2. Building the functional product from consumer expectations

General properties such as liking, use, convenience, safety, health, storage life, and consistency of quality and safety have to be converted into quantitative measures of specific product attributes with a required statistical framework. Sensory characteristics, such as appearance, aroma, flavour and texture, are developed into physical measurements, chemical constituents or sensory scores. The critical and important attributes, such as protein content, hardness, specific or general bacterial levels, acidity, solubility, and significant flavour(s), have to be identified for each product, and the required levels of these built into the final product specifications.

In studying food processing, it is important to identify:

- the critical and the important attributes of the final product
- levels of the critical and important attributes that are acceptable
- sensitivity of the product attributes to changes in processing conditions.

1.3.3 Product specifications

The industrial food processor combines ingredient product attributes into product buying specifications; today, these are very often set in conjunction with their industrial customers. The food manufacturer defines the product specifications for the final consumer products using the consumer knowledge from product development, but also with regard to regulatory and retailer requirements. Such groups as supermarket chains and multinational food manufacturers routinely use sophisticated product specifications. To produce food products with the required levels of attributes in the product specifications, the reactions producing these attributes need to be understood and controlled in the processing. This is illustrated in Fig. 1.3.

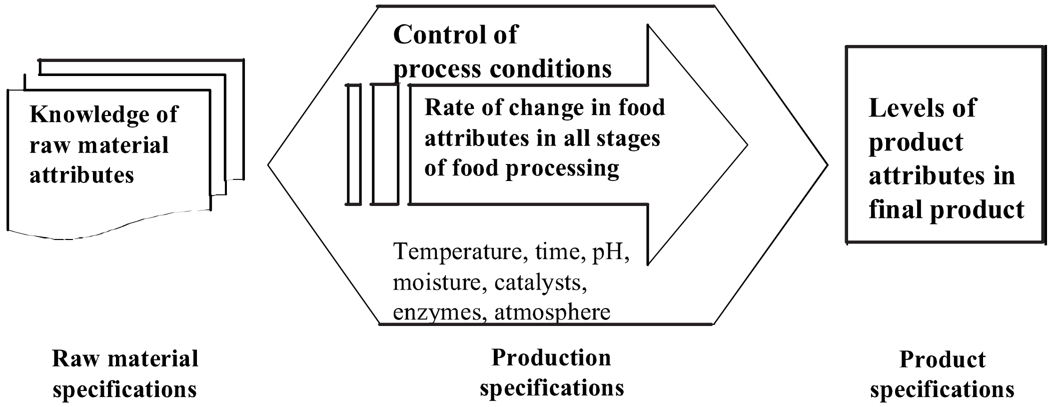

Fig. 1.3. Specifications in food processing

The sheer power of modern chemical analyses going down to parts per billion and the use of such tools as mass spectrometers, tristimulus colour meters, bacterial serotyping, and the continual emergence of new techniques, have provided the wherewithal for the buyer to discriminate almost infinitely. Additionally, if customer-buying specifications were not sufficiently demanding, governments and regulatory authorities are reacting to the substantial pressures imposed on them and exercising their powers ever more extensively. They have justifiably serious concerns for maintaining public health and safety. This is generating fresh stipulations all the time, for example on newly uncovered pathogens and including such processing-resistant entities as the prions, suspected of causing *bovine spongiform encephalopathy* (mad-cow disease) and thence perhaps variant Creutzfeldt-Jakob disease in people eating beef. In addition, regulations are being increasingly demanding on health statements and implications in advertising, for example for nutraceuticals and other foods claiming to be active for this or against that. All of these imply detail in food contents, which have to be properly certified by the processors and legally defended if needed. These requirements are demanded, not only in the food as it is initially placed on the shelves of supermarkets, but also increasingly until some nominated date thereafter.

Each process usually affects several specified attributes, which can be classified as critical, important and unimportant. For example, some of the attributes in orange juice are described in Example 1.1; there are important attributes, such as flavour and aroma, related to consumer acceptability, and a critical attribute, pathogenic organisms that could cause food poisoning.

Example 1.1: Important and critical attributes of orange juice

Fruit juices, such as orange juice, when newly extracted have the flavours and aromas of the original fruit. Many of the especially attractive features diminish gradually with time. The period of time the flavours and the aromas are retained depends on the particular fruit and ambient factors such as temperature and oxygen access. By using techniques such as chromatography, the gradual flavour losses can be monitored, and, by reference to sensory panels, quality thresholds can be set up. For example, the times needed under particular conditions to reach the level of flavour loss that is just detectable to trained panellists can be used as guides and references by the industry and retailers. Also, at the time of extraction, actual and potential off-flavours can arise, such as from citrus oils in the peel of the fruit.

More critically, pathogenic microorganisms can contaminate the juice. These pathogens constitute such a significant health hazard that, in some jurisdictions, notably the USA, legal regulations demand that the packed juice must be subjected to a process sufficient to reduce the numbers of the most resistant pathogens in the finished juice by a factor of five log. cycles, or else the food must be given a warning label that may be detrimental to marketing. This imposes a requirement on the processor to identify the most resistant pathogens in the product, and to ascertain the kinetics of their destruction. Any approved process can be used to ensure that the product meets the stipulations of the regulation with regard to pathogen reduction. This process may be pasteurisation, which is heat treatment, but it may also be one of a number of non-thermal processes, such as high pressure or irradiation.

Adapted from Mermelstein (3)

The attributes measurable in a food can be ranked as critical, where levels are mandatory (because of safety, regulations, contractual stipulations, company policies, strong consumer reaction), very important, where they are significant contributors to quality/value/market appeal, and then range down to unimportant. In processing, critical attribute levels must be maintained, very important ones should be maintained (subject to economic/plant criteria), whereas unimportant ones may not even be recorded (unless used as indicators of processing or product improvement).

Think break

Drink some UHT liquid milk and:

* Identify all the sensory attributes from first looking at the milk in the glass to the final swallowing.

Contd..

Think break (contd)

* Group the sensory attributes into critical, important and unimportant.
* Choose the sensory product attributes to use for measuring the effect of changes in processing conditions.
* Decide what are the critical safety and nutritional attributes that must also be used to control the process.

1.3.4 Sensitivity of product attributes to processing conditions

A continuing problem in processing is assessing the sensitivity of critical and important attributes of the final product to changes in the controllable process variables such as temperature, atmosphere, moisture, catalysts, enzymes and, most importantly, time.

For example, bakers have seen batches of freshly baked bread and biscuits emerging from the oven with the colour of the crusts somewhere between overcooked and burned, and pondered hard whether they should all be rejected, or the darkest culled out, or maybe all of them let go to the market? In any event, it signals losses, even if only in consumer satisfaction. Appearances are important, and the surface on the top of the loaf or the biscuit is just so prominent. Obviously, temperatures have been too high somewhere in the oven or the loaves were spending too long there. Significant questions lie not only in the setting of the temperatures and time but also in the precision of controlling them. The complex relationships between time and temperatures determine the extent of the browning reactions that bring colour and flavour to the crust of the bread, but can also lead quickly to burning and charring. Would a drop in the oven temperatures (and if so how much) and/or shortening the times (and if so how much) allow the oven to produce paler and more consistent crust colour? But would this affect the texture of the loaf, making it doughy? Or would the shelf life of the loaf be reduced by growth of moulds?

These same broad questions permeate much of processing. ‘Trial and error’ experimentation will always bring solutions, but these experiments may be quite lengthy and expensive to work through, and they may still end up some distance from the best solution. When there are several simultaneous reactions proceeding in some process, there are trade-offs that have to be made amongst the processing conditions and they can almost always be made in a host of ways. Which are better, and is there a best? The sensitivities of the various critical and important attributes to processing conditions such as time and temperature need to be evaluated before selecting the optimum process conditions. Optimum process conditions for one attribute may be less than optimum for another, so compromises need to be made. In Example 1.2, this is discussed in regard to the pasteurisation of milk, one of the early examples of the use of reaction technology in processing, although such implications were only partially appreciated at that time.

Example 1.2: Pasteurisation of milk – choosing the processing conditions

For many years, and in most countries, cows' milk for human consumption has been treated by pasteurisation, in which it is subjected to controlled heating. This is motivated almost totally for health reasons, and has had a demonstrable and beneficial effect on public health. Therefore, the criteria for the treatment were dominated by the conditions that provided the consumer with safety against organisms of concern, such as *Mycobacterium tuberculosis* and *Coxiella burnettii*. Regulations to demand a specific processing condition of temperature and time for liquid milk were imposed, in some countries virtually as soon as knowledge to do this was available.

Experimentation later showed that a number of process conditions could provide equal protection from the microorganisms. Processes stipulating higher temperatures and shorter times became possible, especially with the evolution of plate heat exchangers. Although clinical and public health opinion was conservative, and regulations were not easy to change, the high-temperature/short-time processes were accepted by the regulators.

All of these processes caused sensory changes to the milk quality such as some browning and caramelisation giving a 'cooked' flavour, as well as some nutritional changes and destruction of vitamins and enzymes. To be on the safe side, most processors erred on the side of over-processing. And so milk with appreciable cooked flavours became fairly general and it was often all but impossible to buy anything else.

However, investigation of the various processes occurring during the pasteurisation showed that the browning, vitamin, enzyme and bacterial changes behaved systematically. Therefore, by using reaction technology, the sensitivity of the various reactions to the processing conditions could be found. A range of new process conditions were then specified that guaranteed that the product would agree with the product specifications set by the company, regulators and the consumer. Under these processing conditions of time and temperature, the required health stipulations could be met, but the extent of other detrimental reactions and thus of unwanted changes in sensory and nutritional attributes could at the same time be minimised. With knowledgeable process control design and operation, the sensory changes were virtually imperceptible to the customer. This created a superior product for the consumer, but one that was equally and adequately safe.

Adapted from Lewis & Heppell (4)

1.4 New Product Design

Technology push, while being only part of the whole product development (PD) strategy motivation, can be a very powerful tool in the generation of new products. For this to happen, firstly the processing technology has to exist or be invented, and secondly the technology has to be implemented. Scientific and technological knowledge is the basis for the processing technology, and, in particular, reaction kinetics and reaction technology. Every encouragement is needed to expand the fundamental food processing knowledge base so that it can be available for future product design. This knowledge is needed over the broad landscape of food raw materials and the totality of their possible changes and combinations. It can then be focused and directed to particular product development and commercial opportunities, and the technological knowledge implemented in the industrial situation, in the creation of a product that the market will buy and continue to seek. It may seem straightforward, but the implementation generally proves to be the most difficult and the most expensive part of the PD Process in practice.

Therefore, there is a call for more systematic understanding of the processes and the process details, so that processing knowledge can be adapted and applied in new product design, particularly in developing innovative products. Knowledge of rates of reactions can produce a range of new products, such as shown in Example 1.3, where different heat treatment regimes, together with membrane separation, are used to separate proteins from milk and produce a range of food ingredients.

Example 1.3: Milk protein products

Milk contains a considerable range of proteins, and the individual proteins or groups of proteins have all manner of properties that make them both useful and nutritious as ingredients in other foods. Between the various protein constituents, the properties vary considerably, and with them demand and price. It is therefore of real benefit to be able to process milk so that these proteins can be separated, generally into banded groups with specific properties, such as the caseins. It is worthwhile that such groups of proteins, if possible and economic, be commercially produced and marketed to appropriate food manufacturers for incorporation into their products.

Whey was produced in huge quantities in the dairy industry as a by-product of the manufacture of butter and cheese, and was a major waste problem. Research was then undertaken into the nature of the whey proteins, and into their properties. In particular, the effect of varying the time and temperature of the heat treatment, and also the pH, on the rates of denaturation of the different proteins and their precipitation from the whey were studied. These rates were found to vary with the different

Contd..

Example 1.3 (contd)

proteins and led to systematic methods of separating the proteins in the milk, when combined with membrane technology. Both the separation of the protein groups and the properties of the separated proteins were related to the conditions of the heat treatment. Such processing needed to be treated systematically and controlled carefully so as to produce protein products with specific properties.

Over the years, these separations have become more sophisticated and have led to a wide variety of dairy protein ingredients and a substantial industry.

Adapted from Earle, Earle & Anderson (5); Huffman (6)

In the design of new products, careful thought has to be given to the consumer needs and wants and also to the production requirements. This is especially so for the continuous, large-scale operations that mass production and marketing demand. In the food industry, product design and process development have to be integrated throughout the PD Process. Central to the product design specification and its outcomes are:

- the changes that processing is designed to accomplish,
- the ways in which these changes materialise, and
- the controls needed to ensure that they will, and always will, end up with the product that the consumers said they wanted and would buy (7).

Further, knowledge in more detail of these changes in processing can expose practical possibilities, which can be incorporated in the product design in order to make even more exciting and adventurous foods than might otherwise arise.

By their very nature, new products imply creation and invention. These processing activities, bringing in the novel and the previously uncharted, need the widest and deepest tool bags to use in their explorations and trials. Reaction technology with experimental designs can provide the knowledge base for these new developments in the future. In Example 1.4, it is shown that the study of two reaction rates – destruction of pathogenic organisms and protein denaturation – could lead to a new product – eggs that have been pasteurised in their shells to satisfy consumer demands for increased product safety.

Example 1.4: Developing pasteurised eggs in their shells

The potential presence of pathogenic microorganisms in foods is a problem of great importance to human health. These organisms, for example *Salmonella* spp, can be reduced by heat treatments to numbers that make them unimportant as a health problem. But the egg proteins are also denatured by heat treatments.

Investigations into rates of protein denaturation and of pathogenic organisms' destruction during heat treatment showed that, for some important vegetative pathogens, the effect of increasing the temperature on the rate of destruction was significantly less than that on the protein denaturation. This meant that, at longer processing times at lower temperatures, the destruction of pathogens was much faster than the denaturation of proteins. In practice, this implied that long-duration heat processes at relatively modest temperatures could achieve pasteurisation without undesirable concomitant coagulation of proteins.

It was claimed that this could be applied to treatment of eggs in their shells. By this treatment, a new product, an egg that is still soft but is at the same time safely pasteurised, can be produced and marketed.

Adapted from Hou, Singh, & Muriana (8); Polster (9)

Think break

Consider three important product specification issues, for example labelling, health, and safety.

* Relate these to the demands they impose on the two food processing operations lines that you selected in the first think break on page 3.
* How might the processing need to be modified if these specifications were tightened?
* What further information and process knowledge would be needed to enable this to be implemented?
* How might these be related to any costs and disadvantages that might follow non-compliance?

1.5 Product Shelf Life

The time that a food lasts as an acceptable and safe product in distribution, in storage, in marketing and in the home, has always been important. Short shelf life can limit value and availability and may even generate serious shortages when replacement foods are expensive or unobtainable. It is only recently that it has become common, and often legally required, to specify use-by dates or something equivalent on the foods or their packaging. Such claims raise many immediate problems and some ambiguities. Another important determinant of acceptable shelf life is nutritional and compositional labelling. For example, if the levels of labile nutritional compounds such as vitamins change with time and with storage temperatures, does the label carry the initial concentration when packed, the concentration at the nominal expiry data, or some mean concentration between these two? And whichever is chosen, how does it relate to temperature variations in storage, which are all but inevitable under any normal conditions? And if, as say with vitamin A, a high content may be detrimental to health, how are the consumers to evaluate their intakes?

Difficult as these questions may be for the customer, they can be worse for the retailer or the wholesaler faced with queries and complaints, and even, as society becomes more punctilious and litigious, cause expensive proceedings for the food manufacturers. Food manufacturers may have extensive product testing regimes, and temperature- and atmosphere-controlled storage, but there still remain elements of ambivalence that are almost built into the system. The retailer may attempt to opt out, taking large margins of safety by specifying unduly short storage time availability, but this is expensive, and bothersome in terms of stock rotation, may be bad publicity for the store or the product or the product line, and may cause large product returns from the retailer to the manufacturer. Finally, there is the uncertainty once the food gets into the domestic situation, where the potential consumer may be unsure, variable, and capricious in meeting the demands made for storage on the home shelf or refrigerator before consumption. The benefit of any doubt will seldom go to the manufacturer if the food is below par when eaten. ‘Keep refrigerated’ is of doubtful assistance as home refrigerators are not noted for the high quality of their temperature controls; nor is space always available in them for longer-term holding, however justifiable.

1.5.1 Studying shelf life

In studying the shelf life of a food, there needs to be knowledge of:

- product attributes significant to acceptable quality
- critical and important product attributes, their acceptable levels and any statistical variations in attribute levels that are allowable
- changes of product attributes with time
- reactions causing these changes, many of which are spontaneous reactions and time-dependent
- rates of these reactions, which may vary for different product attributes
- effects of storage variables on rates of reactions.

It is important in studying shelf life to control the storage variables, for example time and temperature, that affect the rate of deterioration. Storage variables are shown in Table 1.II.

TABLE 1.II
Storage variables affecting the shelf life of foods

Food materials	Environment	Packaging
Microbiological quality:	**Temperature**	**Permeability to:**
Pathogens	**Water activity**	Oxygen
Spoilage bacteria	**Atmosphere:**	Water
Yeasts	Oxygen	Carbon dioxide
Moulds	Carbon dioxide	Ethylene
Composition:	Inert gases	Odours
Moisture	Ethylene	Solvents, oils
Acidity/pH	**Light**	**Light transmission**
Sugar	**Microorganisms**	**Packaging migration**
Salt	**Pests**	**Product/packaging interaction**
Preservatives	**Contaminants**	

Adapted from Singh (10); Ellis (11)

Perhaps the first really extensive study reported on shelf lives of foods was carried out in California in the 1950s on frozen foods (12) This examined the premise, then commonly held, that, once fully frozen, foods in general were substantially stable. The researchers studied frozen fruits, vegetables, meats and fish and, by using large resources of people, sensory panels and time, effectively established that this was not true, as shown in Example 1.5.

Example 1.5: Shelf life of frozen foods

In studying the frozen storage of fruits, vegetables, meats and fish, some chemical and sensory attributes were measured. Samples after cold storage at a constant temperature were compared with samples held at a temperature considered low enough for no change to occur. Sensory difference tests and statistical analysis techniques were used to compare the test and control samples. Shelf-life expiry was the earliest time when a difference between the quality of the test and control samples was statistically detected by a panel trained to assess the 'overall quality' of the food.

Major difficulties arose in carrying out this study, in particular the time scale of years found to be needed, and the sensitivity to temperatures that required much more precise and reliable temperature controls than were normal in cold stores. Coupled with this was the need to train sensory panels to give reproducible judgements over these long periods.

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Example 1.5 (contd)

The research showed essentially that deterioration occurred systematically at rates dependent on temperature relationships well established in the chemical literature. From these results, the practical storage lives for frozen foods were calculated, which have been updated through the years, as shown in Table 1.III.

Adapted from Van Arsdel *et al*. (12); Singh (10); Erickson & Hung (13)

The results of these time-temperature tolerance studies gave both an impetus and a basis to kinetic understanding of food product behaviour on storage. Notably, it proved that shelf lives of food products conformed generally with what would be expected from reaction technology, and were systematically predictable in terms of the food material and the conditions of its storage. They led to the concept of practical storage life (PSL) on which to base storage and distribution specifications. The PSL of frozen foods can be defined as 'the period of frozen storage after freezing of an initially high-quality product during which the organoleptic quality remains suitable for consumption or for the process intended' (14). Some typical PSLs for frozen foods are given in Table 1.III.

TABLE 1.III
Practical storage life of frozen foods

	Practical storage life (months) at		
	-12 °C	**-18 °C**	**-24 °C**
Peaches, apricots, cherries, raw	4	18	>24
in syrup	3	18	>24
Green beans	4	15	>24
Cut corn	4	15	>24
Peas	6	24	>24
Carrots	10	18	>24
Beef carcasses	8	15	24
Beef minced	6	10	15
Fish lean	4	9	>12
Fish fatty, glazed	3	5	>9

From IIR (4)

Shelf-life testing has led to substantial benefits for:

- consumers, so that they gain protection from codes, for example that of the Association of Food and Drug Officials of the United States (AFDOUS), and from adequate labelling of shelf-life expectations at certain temperatures;

- processors, so that they can reliably act to ensure high quality in their products as delivered to the customer;
- retailers and warehousemen, for stock control and rotation;
- designers, so that they can design storage and distribution equipment to deliver designated shelf lives for their products throughout distribution and marketing.

1.5.2 Extending product shelf life

Preservation has always been a major issue in food production and marketing, but the measures taken to extend it in the past were largely empirical and based on observation and *ad hoc* experimentation. Today, better identification of the critical product attributes and the storage variables determining product life allows for more scientific exploration of their changes and dynamics. This allows for the setting of specifications and the use of modern controls, leading to prevention or at least reduction of deteriorative changes. This degree of knowledge may not always be available or determinable in any particular case, but it can be built up through basic research. The real advantage of improved understanding of deterioration rates lies in the much more accurate predictions of these rates and of the resulting shelf lives of the foods. For example, knowledge of the effects of temperature on reaction rates can quantify the effects of reduced temperatures of storage. Also from this reaction rate/temperature relationship can come more precise evaluation of the benefits of any particular temperature level and the extent of tolerance of temperature fluctuations. Because lower temperatures and closer controls cost more, the product quality benefits of these can be balanced against their additional costs, and optimal conditions found and stipulated for warehousing and for protective packaging. An illustration comes from research to improve the quality of fish after catching, as shown in Example 1.6.

Example 1.6: Deterioration of fish after catching

Observation shows that fish are generally in their best condition immediately after catching, and that their quality changes detrimentally thereafter. Over the years, a number of chemical, biochemical, and physical tests have been evolved to measure these changes, and also there has been extensive use of sensory panels. These studies have shown that the acceptability sensory panel scores diminish systematically after catching, and off-odours and off-flavours and their related chemical constituents increase. The rates of these changes are temperature-dependent.

There is, of course, appreciable experimental variability and therefore need for statistical treatment of the data, but they clearly show that the

Contd..

Example 1.6 (contd)

deterioration of the fish quality, by whatever measure, is systematic and statistically reproducible, and that it follows regular kinetics. It shows that the critical variable is the temperatures at which the fish are held for all the time after catching, and that the dependence of rates of deterioration on temperature is in accordance with the general behaviour of chemical reactions.

An important outcome for the product quality is that decreasing the temperature as soon after catching as possible and also having low temperatures in holding and storage, are beneficial. The results allow calculation of the extent of the benefit that can be expected under a particular temperature regime and matching the value of the benefits of lower temperatures against the increased costs of the processing.

Adapted from IIR (15); Earle (16)

In Table 1.III, the storage life of lean frozen fish is shown as increasing from 4 months at -12 °C to 9 months at -18 °C, and greater than 12 months at -24 °C. Fatty fish has shorter frozen storage life, but it is also increased from 3 to 5 to >9 months at, respectively, -12, -18 and -24 °C.

Think break

Compare the use-by (or best-by) dates on ten different chilled and frozen foods in your local supermarket.

* Describe the processing methods for these products.
* How do the use-by dates relate to the processing method?
* Outline how modifying the processing might extend these dates.
* Find the packaging and the storage temperatures for these products.
* Outline how modifying the packaging and the storage temperatures might extend the dates.

1.6 Storage and Distribution Design

The design of foods includes the design of product, process, and package, as well as the conditions in the distribution system. A great deal of design has been based on reactions involving microorganisms, oxidation, browning, bleaching, vitamin loss, and protein change, so the industry has quickly adopted reaction technology and the use of models to predict and control the shelf life of new foods. The factors that can influence the shelf life of foods are raw materials and product formulation, ambient conditions such as water activity and availability of oxygen, processing and hygiene, packaging materials and system, storage, distribution and display.

The product formulation has a profound effect on the shelf life. Changing the moisture content affects markedly the rates of growth of organisms, browning, bleaching; addition of acids, sugars and salts can affect not only the microbial growth but also physical changes such as crystallisation. By using predictive models, the microbial stability of a product formulation can be rapidly assessed (17). The process can also be designed, using models of inactivation, to ensure that the target microorganisms are effectively destroyed. The packaging design is the link between the design of the product/process and the distribution system. A most important function of food packaging is the protection of the product from environmental conditions, such as light, water vapour, gases and odour, and from internal changes such as loss of moisture, and volatiles. It has to be related to the product qualities and also to the conditions of storage and transport.

The most important of these storage conditions are time and temperature. During distribution, the food will be subjected to different time/temperature regimes. If these are known, then predictive models can be used to follow their effect on the product attributes throughout and at the end of the distribution chain. This can often involve shelf-life trials if there are not sufficient data available. Some steps in design of product shelf life are (18):

- Assess product formulation
- Assess processing conditions
- Specify the product attributes
- Check the history of similar products
- Predict rates of deterioration for critical and important product attributes
- Reformulate product, change process conditions
- Design packaging for product prototype
- Predict storage and transport conditions
- Test shelf life under predicted conditions.

Well-planned shelf-life tests are needed in all product development projects to ensure that the final packaged product is acceptable. There needs to be knowledge of the critical and important product attributes, methods of measuring them, and the conditions to be met in the distribution system, so that the tests can be realistic and applicable. Reaction rate models can reduce the experimental time and work in shelf-life testing.

1.7 Food Processing: Reaction Technology Base

The processing chain in the food system, as shown in Fig. 1.4, is complex and interactive.

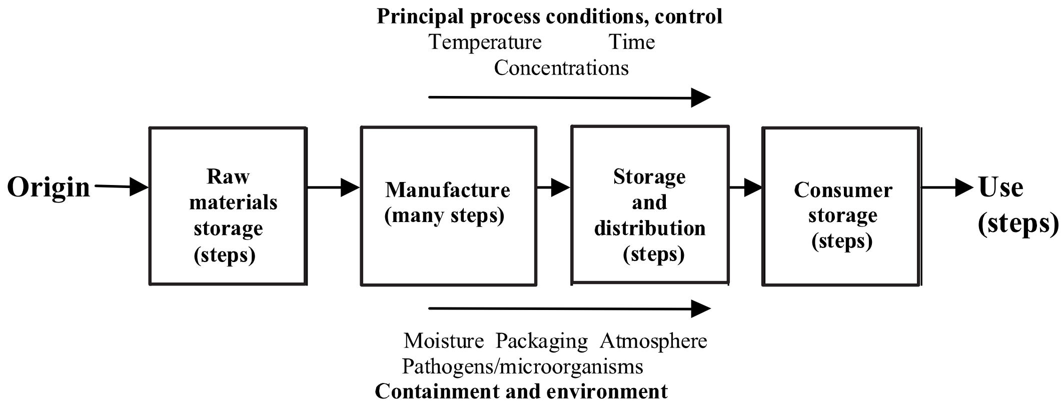

Fig. 1.4. The processing chain

Reactions in one section of the food chain can continue in the next section of the chain; reaction products formed in one section can be the raw materials for reactions in the next section; reactions in a section can also affect other reactions in that section. A problem in developing food processing as a quantitative technology is knowing the reactions and their inter-relationships, and controlling them to give the desired product. Food processing is manipulation of biological materials and therefore has to cope with variation in the raw materials; it is also not an exact process, so there is variability in the processing conditions. The variability may be within set limits but it may still be enough to cause significant changes in the reaction rates in the processing and in the attributes of the final product.

1.7.1 Process variables and their variability

Two groups of variables that affect processed foods are:

- composition of the food, in terms of its components, which can be measured by their concentrations (C)
- processing and distribution environment, principally temperature (T) and time (t), but also other variables, such as those for storage shown in Table 1.II.

Natural variation of the incoming raw materials is an uncontrollable factor that affects processing. These raw materials are almost totally biological in origin and this brings with it dependence on the weather, the time of the year, incidence of contamination and pests, so that there is an inherent variability within materials. An extreme example is the wine industry, which has simply had to accept seasonal variations in the solar insolation and rainfall, which produce, amongst other things, quite major changes in the sugar, acid, and flavour constituents of the resulting grape juice from a given vineyard. This industry has found it quite impossible to accommodate variations overall, although some adjustments can always be made. So the variations are simply passed on to the consumers, who have had to become accustomed to accepting the variation by receiving substantially differing products all with similar labels, often at different prices, and differentiated for the knowledgeable according to the year of the vintage. But this is unusual. In most circumstances, ways have to be found to check out the quality of the raw materials before processing, and then to make appropriate responses in selection, formulation and processing, to ensure a satisfactorily uniform product.

The critical attributes of the raw materials have to be identified, measured and analysed prior to the processing, and then the appropriate treatments or strategies produced to cope with the new, and often still changing, situation. Many of the attribute changes encountered can be subtle and they can also, and frequently do, interact. For example, a reaction can be highly dependent on pH, which can vary in the raw material and can change during processing owing to the chemical reactions occurring in the process. The pH can shift with the quality and the maturity of raw materials, and, where large quantities of these are procured from a number of sources during a growing season, the variations can seem almost random and arbitrary. So all of the relevant factors have to be monitored, and the process conditions adjusted accordingly to maintain consistency in the product. To do this, it is essential to understand as completely as possible the reactions and interactions that arise, their effects on the final food product attributes, and the ways in which the process operators can achieve uniformity in their products.

Processing conditions can also vary. Inevitably in factories under ordinary working conditions there is a variable demand on the services such as the steam supply. Although there is control equipment and the services staff makes every effort, there may still be times when the working steam pressure falls below the stipulated level, or indeed at other times rises above it. These temperature changes give rise to reaction rate changes, and therefore to necessary processing time changes that can be quite dramatic. In Example 1.7, there is a discussion of variation in steam pressure and its effect on reaction rates and therefore on processing.

Example 1.7: Effect of variation of steam pressure on reaction rates in canning

Consider a canning process normally taking place at a fixed temperature of 121 °C, i.e. 2 Bar steam pressure. Time for destruction of the standard microorganism (*Clostridium botulinum*) can be calculated for this temperature using canning calculations. If the absolute steam process pressure were to fall by as little as 9% from 2 Bar, the time needed to

Contd..

Example 1.7 (contd)

accomplish the same extent of processing for destruction of the standard organism would double. The sensitivity of the microorganism to change in temperature works out to be 26% per degree C. Technologists, and perhaps process operators, should easily be able to calculate what changes in process time would be necessitated by a change occurring in their process temperature. And this does not apply just to falls in processing rate; over-processing, though it may be quite safe, will almost inevitably have detrimental effects on quality.

The following questions arise: How can allowances be made for the changing conditions? And if the conditions persist what changes in schedules must be made to compensate? It is the final product that matters, and this is related to the integration of the changes in the food raw material through the processing cycle. How must the variables that are under the control of the operators be manipulated so as to give, reliably, the desired product?

Think break

From Table 1.III, minced beef has a practical storage life of 6 months at -12 °C, 10 months at -18 °C, 15 months at -24 °C.

* If the temperatures throughout your cold store can only be reliably controlled to ±3 °C, and you need to store the meat for 12 months, discuss how you would go about selecting the set temperature for the store.
* If the temperature could be controlled to ±1 °C, how would this affect your choice of store temperature?

1.7.2 Process control

Control of the process can be manual but is increasingly automatic. It is only adequate if:

- sufficient information about the process, including any deviations from the desired levels of the process variables, is available at all relevant times;
- this information can be properly interpreted by either operator or automatic controller;

- the resulting response is sufficient and fast enough to reduce any deviation to a negligible level before the product goes out of specification.

This is an ideal situation to which any real situation only approximates. But modern control equipment with precise and extensive instrumentation can reduce out-of-specification product to a very small fraction of production, so long as the control equipment can follow the processing dynamics adequately and find and ensure a quick corrective response to deviations from the set points. This relies on an adequate understanding, particularly of the process dynamics and also of any interactive possibilities that might upset the situation and in particular lead to over-rapid responses putting either intolerable strains on equipment or instabilities into the processing.

1.7.3 Ensuring product quality and safety in food processing

Control of product quality to within the limits needed for acceptability and marketing of the product is essential for continued access to supermarket shelves and for repeat buying by consumers. These limits are tightening all the time as greater sophistication and greater market power are sought and obtained by both the retail trade and the consumers. Because potential fluctuations in quality have both systematic and also apparently random elements, statistical techniques are the obvious method to use in process control. This has been done over the years with great success by the industry and has yielded real and obvious improvements for the customers.

In the demands made on the industry to reduce any conceivable risk in food products, the conceptions of risk range from the concrete to the vaguest, and at times well beyond anything quantifiable with present knowledge. The 'precautionary principle' basically implies that any incompletely quantifiable risk that exists, however unlikely its occurrence, is unacceptable. Since, from its definition, absence of risk cannot be proved, the only way in which to meet such objections and continue in business is to continually attack ignorance, increase knowledge of reactions in processing, quantify them and reduce their variability.

One powerful way of doing this is by pursuing the components in the food all the way as they move from the raw materials to the consumer product, and then seeking to give the final product a clean bill of health and optimum quality. The clearance must largely come from the lack of harmful outcomes in the historical record. This can be accumulated from information on all components, stemming from analysis and the understanding of what happens in processing. One way of dealing with the danger is to focus on 'food safety objectives', which would define the ultimate level of, for example, pathogens in a given product, and then study the effects of time, temperature and other conditions on the destruction of the pathogens in the process. Although it has considerable practical difficulties in implementation, this use of reaction rates could define the necessary processing that would always ensure a safe product to a stipulated extent or level of risk, as discussed in Example 1.8.

Example 1.8: Ensuring safety in foods

Pathogenic, and toxin-producing microorganisms are a continuing problem in food safety for the food industry, and food safety objectives need to be set. A safety objective would be specific for a particular organism, and would relate to the infective dose, such as, for example less than 100 cfu/g of *Listeria monocytogenes* present in a meat product at consumption.

Meaningful assignment of safety objectives needs to take account of:

- variability of infective dosages and of individuals taking them in
- expense and practicability of meaningful sampling
- probable maximum intake of the food at one meal
- validity of infective dosage as having general applicability.

With bacteriological standards, the problems are substantial, including great biological variation.

To set such a target would need knowledge of the actual *Listeria* input from the raw materials and the environment, followed by reaction technology control of the processing to ensure at most the demanded final levels. Since bacteriological sampling is destructive, time-consuming and expensive, the final outcome would virtually have to be a statistical final risk level at an extent of processing modulated by a combination of Hazard Analysis and Critical Control Point (HACCP) techniques, and final product sampling. The actual risk level achieved would result from the balancing of: sampling and testing adequacy and costs, overprocessing quality losses, raw materials variability, and the statistical risks of infection and reinfection. But it must ensure safety in the final product.

Adapted from Newsome (19)

Think break

In the canning of condensed milk, discuss how temperature could be varied:

* to reduce the time needed to sterilise the milk;
* to decrease the ‘cooked milk’ flavour in the final product after sterilisation.

And then:

* Discuss how you would organise experiments to determine the time and temperature of canning so that the ‘cooked milk’ flavour could be at a minimum with the safety of the milk still ensured.

1.8 Food Process Design

The task of the designer of food processing lines and of the component machinery that makes them up is still a mixture of art, science and technology. Even the best designer does not always either get everything right or produce the most efficient and economical plant. The greatest barrier to reducing the gap between what is achieved and what is achievable is lack of knowledge. Food materials and processes are at best complex and only partly predictable, at worst seemingly arbitrary and even wildly capricious. In part, this comes from their biological and fundamentally unstable character, but occurs also in part because technology has not yet reached out and grappled with enough of the problems to solve even most of the serious ones. Computers are taking an increasing part in modern food plant and process design (20), but their effectiveness is never any better than the understanding of the processing built into their programming. In designing a process and equipment, the effects of changing levels of the process variables on the rates of reactions in the food processing and therefore on the attributes of the end product need to be understood and used as a basis for design, as shown in Example 1.9.

Example 1.9: Designing a new process for freezing meat

In order to supply distant markets in Britain, large quantities, hundreds of thousands of tonnes annually, of lamb carcasses have been frozen and exported from New Zealand. Traditionally, carcasses were first cooled in ambient air for about a day and then frozen by placing in static freezer stores until freezing was complete. In the 1950s, air blast freezing was developed and the whole process was speeded up, with the carcasses being loaded during the day into air blast freezers, frozen overnight, and then loaded into the cold stores. This became general in the industry as it saved a good deal of space and time, and it was convenient.

Then reports started to emerge complaining of a greater incidence of toughness, which had not previously been a problem with these young 3- to 6-month-old sheep. A substantial research programme was undertaken and this brought out more of the detail of the muscle biochemistry and of the *rigor mortis* in the tissue. Essentially, it showed that, until certain post-mortem changes in the muscle had occurred, substantial temperature reductions imposed on the muscular tissue could induce shortening of the muscle fibres and this toughened the meat. These changes were chemical reactions, which were temperature-dependent. Control of temperature changes, in particular sufficient time at higher temperatures for the *rigor mortis* to proceed to or near to completion, would avoid the toughening phenomenon. Therefore, prescriptions for time-temperature conditions, which included a stipulated minimum time at higher temperature before

Contd..

Example 1.9 (contd)

exposure to freezing air blasts, became available to the industry from the research and were adopted. This was later extended to include tenderness increases gained by ageing the meat, and combined into a model.

Adapted from Graafhuis *et al*. (21)

Lack of understanding of reaction technology in process design can lead to design mistakes and cause a great deal of money to be lost in redesign, and in drastic cases a loss of a new product for the market. In designing a new process, it is important to:

- identify the critical and important attributes of the final product
- identify the reactions that lead to these product attributes
- identify the process variables, and their possible variation
- determine the effects of changing the process variables on the rates of the reactions
- choose the required levels for the critical product attributes and the optimum levels for the important product attributes
- select limits of the process variables to give the required attribute levels
- design the equipment to give the required control of the process variables.

Obviously, there are engineering and economic needs, which also have to be considered, but these must not disregard the product needs.

1.9 Modelling Food Processing Using Reaction Technology

The food product developer, the plant operator, and the food engineer, in order to work effectively, all need an accurate prediction of what will be produced from the raw materials if they apply defined processing unit operations to them, such as mixing, blending, heating, cooling, ageing, and so on. Over the years, observation has built up a great store of tacit knowledge in the minds of technologists. The tacit knowledge is constantly actively available, consciously and unconsciously, and is always growing. Today, the huge and increasing body of codified knowledge of the food and scientific literature, and of in-house documentation, is adding to this and bringing increasing possibilities of enhanced technology.

One powerful supplement is to have a quantitative description of the changes consequent on processing set out in terms of all of the significant process variables, and this is commonly termed modelling. Figure 1.3 displays the outline for food processing models based on reaction technology. The model of a food process or part of a process is a mathematical description relating the levels of the process variables and the raw materials attributes to the changes in the product attributes. From these relationships, the levels of the product attributes can be predicted for any raw material attribute level and process level, so that an optimum and safe process can be designed. A model is a codified systematic scheme, developed from one situation and then available to be fitted to all sorts of new situations, which obey the same mathematical equations. It is a quantitative description.

The problems are firstly to assemble a model for a specific food process, and secondly to set it up in a form that is conveniently accessible to those who might make industrial use of it. These are almost never researchers, but include operators, managers, designers, and quality controllers. For them, the model has both to exist and to be conveniently available, because, if it is not, then there will be such a barrier to its use that it will be ignored and the benefits not realised. So this means that complicated mathematics, for example, which all too often has to be invoked to deal with the complexities of real food systems, need to be streamlined and included in easily accessible computer software. For example, the canning industry is an area where quantitative information on bacterial destruction has been built up for many years and is presented in simple packages to all operators when they gain their certificates. Aspects of the canning model are discussed in Example 1.10.

Example 1.10: Predicting adequacy of processing in can sterilisation

Attempts to control the safety of heat-processed foods, particularly in metal containers, first started about 80 years ago. There were substantial difficulties in developing quantitative descriptions of, firstly, the effect of heat on microorganisms in various forms and environments and, secondly, the actual heating process in three-dimensional and often complicated container shapes. Simplifications and approximations were based on the use of only one food-poisoning organism, *Clostridium botulinum*, which was heat-resistant, and the slowest-heating part of the can. The contribution to sterilisation of the cooling phase of the heating/holding/cooling process was neglected at first.

Undeniably, if the process determinant is based on the condition at the least processed region of the can, and the process extent varies because of non-uniform heating, there must be overprocessing. Research, over many years, has produced quantitative evidence of the extent of this overprocessing, which can be thought of as a factor of safety. A question then is, does canning need this added factor of safety for its undoubted practical success? Or was it not so much a factor of safety as a factor of ignorance, and it really was retained because of fundamental uncertainties? This would be less important if there were just the question of safety, where

Contd..

Example 1.10 (contd)

there can hardly be too much, but overprocessing also and inevitably detracts from quality as it continues deteriorative reactions beyond the point of necessary processing.

The theory itself, though it has been very useful and demonstrably successful, has several major questions still to be sorted. One, for example, is insistence on 10^{12} reduction in the standard organism at the least processed region in a can – a region that can be small in volume. The vast bulk of the can contents can receive processing greater by orders of magnitude. Since the whole theory is statistically based, there seems justification to extend statistical and averaging treatment over each processed food unit, in this case a can.

Adapted from Hicks (22); Palaniappan & Sizer (23); Peleg & Cole (24)

Think break

For two dried products – instant whole milk powder, and instant meals used by walkers, sailors and other outdoor sportspeople:

* Identify the critical and important attributes of each product
* Identify the attributes in the raw materials related to the critical and important attributes of the products
* Outline the process for each product, showing the unit operations and their sequence
* Identify the nature of changes that occur in the food materials in each unit operation, such as physical change, chemical change, biological change, sensory change
* Relate these changes to the final product attributes you have identified
* Draw basic models, as in Fig. 1.3, to show the reaction technology in the various unit operations in the two processes
* Consider how you might further study the progress of these changes as they proceed with time, what experimental measurements you might need to make, and what sort of results you might expect to come from these experiments.

1.10 The Challenge

To summarise, important issues for the food industry that will be materially advanced by greater understanding of the technological details of food processing, are:

Converting a craft into an industrial technology. This conversion is essential for the food industry to come fully into the modern era and to unlock the potential benefits that the modern technology and the information age can bring with them. It has started, but can usefully be taken much further.

Making use of possibilities, implicit in food raw materials and their interactions, to most effectively and speedily create new products. Only with knowledge and understanding of the scope that exists to change and convert food materials to satisfy needs can the industry fully develop the new products that should be available.

Knowing and understanding and using reaction technology information. There is much available in the literature, but to be used it must be adapted, and extended to calculate processing dynamics that will apply to industrial situations and systems.

Handling and adapting to changes in food materials. Complex change is implicit in biomaterials and biovariability. Therefore, it arises in so many ways in the thriving and dynamic activity that is food processing. Only the fullest achievable knowledge can set up food processors to deal adequately with the continual change that confronts them in every minute, hour, and year.

Building models of food processing. These can be of any available form – descriptive, visual, mechanical, analogue, mathematical – so long as they can be used to make valid predictions about real food materials in industrial situations. Many process variables may be imperfectly understood, even critical ones, but worthwhile progress can still be made, and results can then be improved, as this is needed.

Defining and improving processing equipment. Equipment must operate reliably and be capable of the precision demanded by the quality product. All too often, equipment used in production can be old, out-of-date, sloppy, inadequate, and not capitalising on modern advances that are available. Obvious modern resources include microprocessors and computers, but there also is a whole host of machinery and control developments to be explored for food applications.

Building judgement. Knowledge of processing that is already in the industry needs to be consolidated and extended from the present tacit knowledge that is concentrated in people and their experience towards more general, codified knowledge. Far from diminishing, this will then be available to enlarge the capacity of everyone in the industry and to improve their judgement, both individually and collectively.

Education in processing. Understanding of the fundamentals, and then applying them to industrial problems and situations are key both to improving present operation and to opening the full power and potential of the future.

These challenges illustrate some of the food processing issues that currently challenge food technologists. They are all important, even if only just a representative selection. The application of reaction technology can help to give solutions or partial solutions to the problems they raise, and demonstrate the promise of further experimental and theoretical study. But, more importantly, it is hoped that the outline of the detail that this book provides will convince readers that the methods are both informative and effective in day-to-day operating situations.

Reaction technology should also provide some important and accessible guidelines for making judgements. Although modern knowledge, modern techniques, and in particular computers, have opened up great ease and apparent reliability in process design and control, unfortunately, computers are totally devoid of judgement on particular cases unless judgement itself can be quantified. This can never fully be the case. It is all too straightforward to buy a program, feed in numbers, punch the start button, and then believe and act on the answer that emerges. Technologists are, and need to be, trained to check independently and to think. Empowering thought is where the reaction technology approach can offer accessible tools that are also logical and powerful.

Think break

Information technology is the current new dimension held to offer great and unparalleled advances in food manufacturing operations.

* Relate information technology to the operations of food processing
* How do you see information technology being used to resolve process control and product specification difficulties that currently trouble the food industry?
* How could reaction technology and information technology be combined in process control?
* Outline what further knowledge of the nature of rate processes is needed so that they could be applied in process design and control with information technology.
* Identify food processes where reaction technology and information technology are used to design and control the processes.

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