Introduction to food process engineering

A process may be thought of as a sequence of operations which take place in one or more pieces of equipment, giving rise to a series of physical, chemical or biological changes in the feed material and which results in a useful or desirable product. More traditional definitions of the concept of *process* would not include the term *biological* but, because of the increasing sophistication, technological advance and economic importance of, the food industry, and the rise of the biotechnology industries,it is ever more relevant to do so.

Process engineering is concerned with developing an understanding of these operations and with the prediction and quantifying of the resultant changes to feed materials (such as composition and physical behaviour). This understanding leads in turn to the specification of the dimensions of pro- cess equipment and the temperatures, pressures and other conditions required to achieve the necessary output of product. It is a quantitative science in which accuracy and precision, measurement, math- ematical reasoning, modelling and prediction are all important. Food process engineering is about the operation of processes in which food is manufactured, modified and packaged. Two major cat- egories of process might be considered; those which ensure food safety, that is the preservation techniques such as freezing or sterilisation, which usually involve the transfer of heat and induce changes to microbiological populations, and those which may be classified as food manufacturing steps. Examples of the latter include the addition of components in mixing, the separation of compo-nents in filtration or centrifugation or the formation of particles in spray drying. Classification in this way is rather artificial and by no means conclusive but serves to illustrate the variety of reasons for processing food materials.

Although foods are always liquid or solid in form, many foods are aerated (e.g. ice cream), many processes utilise gases or vapours (e.g. steam as a heat source) and many storage procedures require gases of a particular composition. Thus it is important for the food technologist or the food engineer to understand in detail the properties and behaviour of gases, liquids and solids. In other words the trans- fer of heat, mass and momentum in fluids and an understanding of the behaviour of solids, especially particulate solids, form the basis of food processing technology. At the heart of process engineering is the concept of the unit operation. Thus the principles which underlie drying, extraction, evaporation,mixing and sterilisation are independent of the material which is being processed. Once understood, these principles can be applied to a wide range of products.

The overall purpose of food process engineering then is to design processes which result in safe food products with specific properties and structure. Foods, of course, have their own particular and peculiar properties: most food liquids are non-Newtonian; structures are often complex and multi- phase; non-isotropic properties are common. In addition to this, hygiene is of paramount importancein all manufacturing steps. The correct design of such processes is possible only as a result of the development of mathematical models which incorporate the relevant mechanisms. Thus it is important to understand the chemical, structural and microbiological aspects of food in so far as they contribute to an understanding of the process, that is, how to develop, design, operate and improve the process to give better performance at reduced cost and, above all, improved safety and quality.

The first step in the design of a process is the conception stage. What is the product to be manufac- tured? What steps will be needed in order to manufacture it? In some cases the necessary steps may be very well known and there is no particular innovation required. As an example take the manufactureof ice cream. Whilst individual products may be innovative to a degree, the essential production steps are well known. There will be a mixing step in which the solid and liquid ingredients are added to the batch, followed by pasteurisation, storage or ageing, freezing and finally filling and packaging. For many food products there is an established way of doing things and there may be no realistic alternative. In other cases it may be far less obvious what the final process design will look like. In each case a simple flow sheet of the process should be prepared.

At this point it is likely to become apparent whether the process is to be batch or continuous. A batch process is one in which a given mass of material is subject to a series of operations in a particular sequence. For example a batch of liquid may be heated, a second component added, the mixture agitated and then the resultant liquid cooled, all within a single vessel. Alternatively the sequence of operations may involve a number of pieces of equipment. In a simple mixing operation,or where a chemical reaction occurs, the composition of the batch changes with time. If a liquid is heated in a stirred vessel the temperature of the liquid will be uniform throughout the vessel, provided the agitation is adequate, but will change with time. Batch processes generally have two disadvantages. First they are labour intensive because of the bulk handling of material involved and the large number of individual operations which are likely to be used. Second the quality of the product may well vary from batch to batch. These problems are largely overcome if the process becomes continuous. Here, material flows through a series of operations and individual items of equipment, undergoing a continuous change without manual handling. Once running, a continuous process should run for a long period under steady-state conditions, that is the composition, flow rate, temperature or any other measurable quantity should remain constant at any given point in the process. In this way a continuous process gives a more consistent product.

The mathematical analysis of a process also highlights an important difference between batch and continuous operation. Continuous, steady-state processes are usually considerably simpler to analyse than are unsteady-state batch processes because the latter involve changes in composition or temper-ature with time. However, the difference between batch and continuous may not always be clear-cut; many individual operations in the food industry are batch (often because of the scale of operation required) but are placed between other continuous operations. Thus the entire process, or a major section of it, is then best described as either semi-batch or semi-continuous.

The second stage of the design process may be called process analysis and this entails establishing both a material balance and an energy balance. The material balance aims to answer the question: What quantities of material are involved? What flow rates of ingredients are needed? In many cases this will be simply a case of establishing the masses of components to be added to a batch mixer. In others it will require the determination of flow rates of multi-component streams at several points in a complex process covering a large factory unit. In food processing the energy or enthalpy balance assumes enormous significance; sterilisation, pasteurisation, cooking, freezing, drying and evapora- tion all involve the addition of heat to, or removal of heat from, the product. Establishing the necessary heat flows with accuracy is therefore of crucial importance for reasons both of food safety and of process efficiency.

A third stage comprises the specification of each operation and the design of individual pieces of equipment. In order to do this the prevailing physical mechanisms must be understood as well as the nature and extent of any chemical and biochemical reaction and the kinetics of microbiological growth and death. Specification of the size of heat transfer process equipment depends upon being able to predict the rate at which heat is transferred to a food stream being sterilised. In turn this requires knowledge of the physical behaviour of the fluid, in short an understanding of fluid flow and rheology. This allows judgements to be made about how best to exploit the flow of material, for example whether the flow should be co-current or counter-current.

Crucial to any process design is knowledge of equilibrium and kinetics. Equilibrium sets the bound- aries of what is possible. For example, in operations involving heat transfer knowledge of thermal equilibrium (the heat capacity and the final temperatures required) allows the calculation of the quan- tities of heat to be removed or added. Equipment and processes can be sized only if the rate at which heat is transferred is known. Each rate process encountered in food engineering follows the same kind of law: where molecular diffusion is responsible for transfer, the rate of transfer of heat, mass or momentum is dependent upon the product of a gradient in temperature, concentration or velocity, respectively, and a diffusivity – a physical property which characterises the particular system under investigation. Where artificial convection currents are introduced, by the use of deliberate agitation, then an empirical coefficient must be used in conjunction with gradient term; little progress can be made in the application of heat transfer in food processing without a knowledge of the relevant heat transfer coefficient.

The overall design of the food process now moves onto the specification of instrumentation and process control procedures, to detailed costing and economic calculations, to detailed mechanical design and to plant layout.