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Separation processes in the food and biotechnology industries

Principles and applications

Edited by A S Grandison and M J Lewis

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Preface

This book concentrates on the more recent methods and techniques for separating food components and products of the biotechnology industry. Each chapter deals with a specific type or area of application and includes information on the basic principles, industrial equipment available, commercial applications and an overview of current research and development.

The introductory chapter gives a brief overview of food composition and properties, and some of the heat and mass transfer considerations in batch and continuous processes. Separations from solids, liquids and gases are briefly discussed. A summary is provided of the more conventional separation techniques such as screening, filtration and centrifugation, and techniques for removing water, such as evaporation, freeze-concentration and dehydration. However, the main emphasis is on separation processes, which have received less attention in textbooks on food-engineering and food-processing operations. It is hoped that this book will complement and supplement many of these excellent texts. Chapter 2 deals with the use of supercritical fluids for extraction processes, with special reference to carbon dioxide. Chapter 3 deals with pressure-activated membrane techniques, and covers the general principles, reviews the applications of reverse osmosis, and serves as an introduction to Chapters 4 and 5, which deal specifically with the principles and applications of ultrafiltration and microfiltration respectively. The separation and recovery of charged particles by ion exchange and electrodialysis is covered in Chapter 6. Chapter 7 discusses innovative separation processes, and reviews some of the methods being actively investigated, some of which are now coming into industrial practice. Much of the emphasis in these chapters is on the separation and recovery of proteins and biologically active ingredients. Chapter 8 is specifically on the methods available for fractionating fat, and covers the upsurge in interest and recent developments in this area. The book concludes with a chapter on solids separation processes, with special reference to particulates. The physical properties which influence the separation are reviewed, together with sieving, screening and air classification. Wet processing methods for extraction are discussed, together with some miscellaneous applications such as dehulling, peeling and cleaning.

Much of the emphasis is on extraction of macromolecules, increasing the added value of foods and recovering valuable components from by-products and fermentation media. Many of the methods discussed are now in commercial practice, whilst others are being vigorously researched.

A. S. Grandison and M. J. Lewis

Chapter 1

Separation processes – an overview

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1.1 FOODS – THE RAW MATERIAL

Food and drink play a vital role in all our lives, providing us with the nutrients essential for all our daily activities, including cell maintenance, growth and reproduction. Although foods are commonplace and much taken for granted, their composition and structure are by no means simple. Firstly, all foods are chemical in nature. For most foods the principal component is water and this water plays an important role in the overall behaviour of that food. One of the most important branches of separation is the removal of water, to save transportation costs and improve microbial stability.

The other components can be classified into major components, such as protein, fat or lipid, sugars, starch and fibre. The minor components include the minerals, which are known collectively as ash, vitamins and organic acids. Information on food composition and the amounts of major and minor components can be found in the *Composition of Foods Tables* (Paul and Southgate, 1978). Table 1.1. illustrates just some of the composition data that is available, for a selection of foods.

Food composition tables are useful in that they provide an average composition. However, some of their limitations are illustrated below, taking milk as an example. It should be noted that similar points could be made about most other foods.

Milk is extremely complex in terms of its chemical composition, containing protein, fat, carbohydrate, minerals and vitamins. There are many different proteins, which can be subdivided into the whey proteins, which are in true solution in the aqueous phase, and the caseins, which are in the colloidal form. The fat itself is a complex mixture of triglycerides and, being immiscible with water, is dispersed as small droplets, stabilised by a membrane, within the milk. The vitamins are classified as water or fat soluble, depending on which phase they most associate with. Some of the minerals, such as calcium and phosphorus, partition between the aqueous phase and the colloidal casein and play a major role in the stability of the colloidal dispersion. In addition, there are many other components present in trace amounts, which may affect its delicate flavour

Table 1.1. Composition of foods (weight/100 g)

	Milk	Apple	Peas	Flour	Beef	Cod
water (g)	87.6 (87.8)	85.6	78.5	13.0	74.0	82.1
protein (g)	3.3 (3.2)	0.3	5.8	9.8	20.3	17.4
fat (g)	3.8 (3.9)	tr.	0.4	1.2	4.6	0.7
sugar (g)	4.7 (4.8)	9.2	4.0	1.7	0.0	0.0
starch (g)	0.0 (0.0)	0.4	6.6	78.4	—	—
fibre (g)	0.0 (0.0)	2.4	5.2	3.4	—	
potassium (mg)	150 (140)	120	340	140	350	320
sodium (mg)	50 (55)	2	1	2	61	77
calcium (mg)	120 (115)	4	15	150	7	16
iron (mg)	0.05 (0.06)	0.3	1.9	2.2	2.1	0.3
phosphorus (mg)	95 (92)	16	100	130	180	170
vitamin C (mg)	1.50 (1.0)	15	25	—	—	—
vitamin B1 (mg)	0.04 (0.06)	0.04	0.32	0.33	0.07	0.08
vitamin B6 (mg)	0.04 (0.06)	0.03	0.16	0.15	0.32	0.33
vitamin D (ug)	0.03 (0.03)	—	—	—	tr	tr
vitamin E (mg)	0.10 (0.09)	0.2	tr	tr	0.15	0.44

• flour – household plain
tr – trace
These values are taken from Paul and Southgate (1978). Figures in parentheses are for milk, taken from McCance and Widdowson's *Composition of Foods Tables* (5th edn) (1991), Royal Society of Chemistry, MAFF. There are slight differences between the reported results.

and processing characteristics and nutritional value, such as trace minerals, organic acids and non-protein nitrogen compounds such as peptides, urea and amino acids. Walstra and Jenness (1984) have listed over 60 components present in milk, at levels that can be readily detected. Milk is also potentially a very unstable material. For example the protein can be made to coagulate by a variety of methods, including heating, addition of the enzyme rennet, acid, salts and ethanol. Also the fat globules rise to the surface under the influence of gravity.

Superimposed on this complex composition is the fact that it is subject to wide variation. Milks from different species differ markedly, and many types of milk other than cow's are consumed worldwide, e.g. sheep, goat, buffalo, camel. Within the same species there are large differences between breeds, and even between individual animals in the same herd. In addition to this, and of prime importance to the milk-processing industry, milk from the same animals is subject to wide seasonal variation, reflecting the change in the animals' diet throughout the year, and the stage of lactation. Factors relating to the handling of milk, such as the pH or the amount of dissolved oxygen, are also important to its stability.

Foods may also be contaminated with matter from their production environment, i.e. soil, water and farmyard. For example milk may be contaminated with dirt, straw, antibiotics, growth hormones, heavy metals, or radionuclides.

In chemical terms alone, there is a great deal of scope for separating the components in milk and some examples are listed:

- water removal to produce evaporated or dried products;
- fat separation to produce creams and butter;
- protein separation to produce cheese or protein concentrates;
- calcium removal to improve stability;
- lactose removal, as a specialised ingredient or for low-lactose products;
- removal of components responsible for tainting raw milk or the cooked flavour of heat-treated milk products;
- removal of radionuclides from milk.

In plant products pesticides and herbicides may additionally be present. Some foods, particularly of plant origin, also contain natural toxins, for example oxalic acid in rhubarb, and trypsin inhibitors, phytates and haemagglutinins in many legumes, cyanogenic glycosides in cassava and glucosinolates in rapeseed (Watson, 1987; Jones, 1992). However, the activity of most of these is reduced during normal processing and cooking methods.

Foods also contain active enzyme systems. For example, raw milk contains phosphatase, lipases and proteases, xanthine oxidase and many others. Fruits and vegetables contain polyphenol oxidases and peroxidases, both of which cause colour changes in foods, particularly browning, and lipoxygenases, which produce rancid off-flavours (Nagodawithana and Reed, 1993).

Therefore foods and wastes produced during food processing provide the raw material for extraction of enzymes and other important biochemicals with a range of applications, especially in the food and pharmaceuticals industries. Some examples are listed in Table 1.2. In the biotechnology industry, similar components may be produced by fermentation or enzymatic reactions and require extraction and purification. Perhaps the simplest example is alcohol, produced by a yeast fermentation, where the alcohol concentration that can be produced is limited to about 15 to 20%, as it inhibits further yeast metabolism. Alcohol can be recovered and concentrated by distillation. For low-alcohol or alcohol-free beers and wines, there is a requirement to remove alcohol. Again distillation or membrane techniques can be used.

A wide range of food additives and medical compounds are produced by fermentation; these include many enzymes, such as proteases for milk clotting or detergent cleaners, amino acids such as glutamic acid for monosodium glutamate (MSG) production, aspartic acid and phenylalanine for aspartame, and lysine for nutritional supplements, organic acids such as citric, gluconic and lactic, and hydrocolloids, such as xanthan gum for stabilising or thickening foods, and a wide range of antibiotics and other medicinal compounds.

In most cases it is necessary to purify these materials from dilute raw materials, which often requires sophisticated separation techniques. In fact a large proportion of the activities of the biotechnology industry is concerned with separations of this nature, which is known as downstream processing. In general, the products produced by bio-processing applications are more valuable than food products, and it is economically feasible to apply more complex separation techniques.