Consumers are increasingly demanding more of their food without any compromise in safety. Dairy-derived ingredients provide today’s food manufacturer with a vast array of possibilities when developing and formulating food products that meet the demands of the modern consumer. Dairy streams (milk, whey, colostrum) represent a rich source of components with valuable nutritional, functional, and biological characteristics. These components, including proteins, peptides, fats, carbohydrates, and minerals, form the foundation for a variety of successful food ingredients used universally in a range of formulated foods and beverages. Commercial success has been built on a sound scientific understanding of these dairy components, their characteristics, and how they interact with other components in a complex food matrix. This underpinning scientific knowledge provides the modern food manufacturer with the means to quickly develop new products with targeted traits. Moreover, this knowledge allows dairy ingredient producers to provide food manufacturers with “tailored solutions” through sound scientific advice on the incorporation of dairy ingredients into their formulations.

Advances in Dairy Ingredients provides an international perspective on recent developments in the area of dairy ingredients and dairy technology. Market and manufacturing trends and opportunities are considered alongside the latest scientific tools that provide the foundation to successfully and rapidly capture these opportunities. Advances in Dairy Ingredients brings together food scientists, industry specialists, and marketers from around the world to provide unique insight into the scientific basis for the success of dairy ingredients in modern food products and a glimpse into the future of new dairy ingredients and foods on the horizon.

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To

Dairy colleague and friend
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Consumers are increasingly demanding more of their food without any compromise in safety. Consumer megatrends include health and nutrition, convenience, price, quality and taste, and reduced environmental impact associated with food processing operations. Dairy-derived ingredients provide today’s food manufacturer with a vast array of possibilities when developing and formulating food products that meet many if not all the demands of the modern consumer. Dairy fluids (milk, whey, and colostrum) represent a rich source of components with valuable nutritional, functional, and biological characteristics. These components, including proteins, peptides, fats, carbohydrates, and minerals, form the foundation to a vast array of successful ingredients used universally in a range of formulated foods and beverages.

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Advances in Dairy Ingredients brings together food scientists, industry specialists, and marketers from around the world to provide a unique insight into the basis for the success of dairy ingredients in modern food products, and a glimpse into the future of new dairy ingredients and foods on the horizon. Market and manufacturing trends and opportunities are aligned with the latest science tools that provide the foundation to successfully and rapidly capture these opportunities. Advances in Dairy Ingredients provides an international perspective on recent developments in the area of dairy ingredients and dairy technology.

Advances in Dairy Ingredients should have wide appeal from academics through to industry personnel because of the mixture of content highlighting dairy science research and development linked to exploitation of this science and technology in the marketplace. The chapters comprising Advances in Dairy Ingredients provide the reader with insight into recent developments in respect to the major milk components, including high protein powders, lactose, specific biofunctional protein isolates, and milk fat globule membrane. The book also explores modern processing approaches for the manufacture of dairy ingredients such as separation technologies, nonthermal processing, and spray-dried emulsions. Unlike other books in the area, Advances in Dairy Ingredients provides the reader with recent developments in the use of dairy ingredients in the texturizing of foods and food microstructure, probiotics and prebiotics as ingredients, what consumers are demanding in
their dairy foods, as well as other foods containing dairy ingredients, and the no-compromise area of dairy safety. Finally, the reader is provided with a glimpse into the future of dairy ingredients and what will be the critical science developments that will underpin commercial success. We sincerely thank all the contributing authors.

We dedicate this book to a long time dairy colleague and friend—the late Bernard S. “Bernie” Horton. Bernie was a pioneer in the use of technology for the processing of dairy fluids, much of which is commonplace in modern dairy factories, and was a champion of dairy proteins as valuable nutritional and functional ingredients. Bernie helped shape today’s dairy industry and contributed to the success that dairy ingredients enjoy in the broader food industry of today.

Geoffrey W. Smithers
Mary Ann Augustin
Advances in Dairy Ingredients
1 Dairy Protein Powders

P. Schuck

1.1 INTRODUCTION

The purpose of the dehydration of milk and whey is to stabilize these products for their storage and later use. Dehydration by spray drying is a valuable technique for water evaporation. Milk and whey powders are used mostly in animal feeds. With changes in agricultural policies (such as the implementation of the quota system and the dissolution of the price support system in the European Union), the dairy industry has been forced to look for better uses for the dairy surplus and for the by-products of cheese (whey) produced from milk and buttermilk produced from cream. Studies on the use of protein fractions with nutritional qualities and functionality led us to believe that they could have several applications (Corredig, 2009; Thompson et al., 2009).

In the past 30 years, the dairy industry has developed new technological processes for extracting and purifying proteins (e.g., casein, caseinates, and whey proteins) (Kjaergaard et al., 1987; Maubois, 1991), such as milk protein concentrate (MPC), milk protein isolate (MPI), whey protein concentrate (WPC), whey protein isolate (WPI) (Goudédranche et al., 1980; Madsen and Bjerre, 1981; Maubois et al., 1987; Caron et al., 1997), micellar casein concentrates (MCC) and isolates (MCI) (Fauquant et al., 1988; Pierre et al., 1992; Schuck et al., 1994a,b) whey concentrates, and selectively demineralized whey concentrates (Jeanet et al., 1996), mainly because of the emergence of filtration technology (e.g., microfiltration [MF], ultrafiltration, nanofiltration, and reverse osmosis). This recent emergence of new membrane separation techniques and improvements in chromatographic resins now provide the dairy technologist with several types of techniques for the extraction and purification of almost all of the main milk proteins.

The most frequently used technique for the dehydration of dairy products is spray drying. It became popular in the dairy industry in the 1970s, but at that time, there were few scientific or technical studies on spray drying, and, in particular, none on the effects of spray drying parameters or on the effects of the physicochemical composition and microbiology of the concentrates on powder quality. Manufacturers acquired expertise in milk drying and eventually in whey drying processes through trial and error. Because of the variety and complexity of the mixes to be dried, more rigorous method based on physicochemical and thermodynamic properties have become necessary. Greater understanding
of the biochemical properties of milk products before drying, water transfer during spray drying, the properties of powders, and influencing factors is now essential for the production of milk powder. The lack of technical and economic information and understanding of scientific methods prevents the manufacturer from optimizing his plant in terms of energy costs and powder quality. In view of the increasing development of filtration processes, the dairy industry requires greater understanding of the effects of spray drying on the quality of dairy protein powders.

A dairy powder is characterized not only by its composition (proteins, carbohydrates, fats, minerals, and water), but also by its microbiological and physical properties (bulk and particle density, instant characteristics, flowability, floodability, hygroscopicity, degree of caking, whey protein nitrogen index (WPNI), thermostability, insolubility index (ISI), dispersibility index, wettability index, sinkability index, “free fat,” occluded air, interstitial air, and particle size), which form the basic elements of quality specifications. There are well-defined test methods for the determination of powder characteristics according to international standards (Pisecky, 1986, 1990, 1997; American Dairy Products Institute, 1990; Master, 2002). These characteristics depend on drying parameters (e.g., type of tower spray drier, nozzles/wheels, pressure, agglomeration and thermodynamic conditions of the air, such as temperature, relative humidity, and velocity), the composition and physicochemical characteristics of the concentrate before spraying (e.g., viscosity, thermo-sensitivity and availability of water), and storage conditions. Several scientific papers have been published on the effects of technological parameters on these properties (Baldwin et al., 1980; Pisecky, 1980, 1981, 1986; De Vilder, 1986; Tuohy, 1989; Jeantet et al., 2008a; Master, 2002) (see Figure 1.1). Water content, water dynamics and water availability are among the most important properties for all these powder properties and powder characteristics.

The nutritional quality of dairy powders depends on the intensity of the thermal processing during the technological process. Thermal processing induces physicochemical changes that tend to decrease the availability of nutrients (e.g., loss of vitamins, reduction of available lysine content, and whey protein denaturation) or to produce nutritional compounds, such as lactulose (Straatsma et al., 1999a,b).

The aim of this chapter is to provide information on the extraction of milk proteins; the principles of spray drying, including equipment and energy consumption; the drying of high protein products, including the relationships between process and product; and the physical, functional, and biochemical properties of the powders. Following an in-depth introduction on dairy protein products, this chapter covers four major areas: the extraction of milk proteins, the principles of spray drying (equipment and energy consumption), the drying of dairy protein products and the properties of these powders.

Figure 1.1 Properties and qualities of powders.
1.2 EXTRACTION OF MILK PROTEINS

1.2.1 Milk proteins

It would be impossible to develop the extraction of milk proteins without prior thorough knowledge of their biochemical and physicochemical properties. A brief description of the milk protein system is therefore important for understanding the principles used before discussing the recent developments in extraction procedures (Maubois and Ollivier, 1997).

Bovine milk contains several that are classically divided into two major groups, that is, caseins, proteins which are insoluble at pH 4.6 and 20°C, and whey proteins which remain in solution at pH 4.6. The protein content of normal milk is expressed as N × 6.38. Milk contains 30–35 g protein/L. About 78% of these proteins are caseins, which consist of four principal components, αs1, αs2, β, and κ, in approximate ratios of 40:10:35:12. In milk, these caseins are organized in the form of micelles, which are large spherical complexes (diameters varying between 50 and 600 nm, average 120 nm) containing 92% proteins and 8% inorganic salts, principally calcium phosphate (Rollema, 1992; Swaisgood, 1992). The structure of the micelles has not yet been fully established, and there is still controversy between the supporters of the submicellar model and those of the coat-core model (Schmidt, 1982; Holt, 1992; Farrell et al., 2006; Horne, 2006). The casein micelles dissociate on removing colloidal calcium phosphate either by the addition of Ca chelating agents (e.g., phosphate, citrate, and EDTA) or by acidification. The casein micelles are partly responsible for the white color of milk. Their stability results from their zeta potential (approximately −20 mV) and from steric hindrance caused by the protruding (“hairy”) C-terminal segments of glycosylated κ-casein, which prevent the close approach of micelles. Removal of these protruding segments by chymosin, the main enzyme present in the neonate calf stomach, results in coagulation of the damaged casein micelles. The integrity of casein micelles is also affected by cooling. At temperatures lower than 4°C, β-casein and Ca phosphate are released into the serum phase of milk.

The whey protein fraction contains several proteins. The main components in bovine milk are β-lactoglobulin (β-Lg), α-lactalbumin (α-La), bovine serum albumin (BSA), and immunoglobulin (Ig), representing approximately 2.7, 1.2, 0.25, and 0.65 g/L, respectively (Alais, 1984). There are many other minor proteins, including lactoferrin (Lf), enzymes (lipoprotein lipase, acid and alkaline phosphatases, lysozyme, xanthine oxidase, lactoperoxidase, catalase, superoxide dismutase, α-amylase etc), growth factors, and hormones (Alais, 1984). The whey protein fraction of human milk is very different from that of bovine milk in that it contains no β-Lg and is very rich in α-La, Lf, lysozyme, and stimulatory factors (bifidus growth factor, epidermal growth factor, bombesin, insulin-like growth factors, etc.) (Fox and Flynn, 1992; Maubois and Ollivier, 1997).

1.2.2 Separation of proteins

Most of the dairy proteins, used as either nutritional or functional ingredients, are marketed in a dehydrated form (see Figure 1.2). The application of different processing steps allows the production of a wide range of different dried and stable intermediate dairy products. Many new uses for these constituents have emerged with the manufacture of formula products, substitutes, and adapted raw materials.

Figure 1.2 summarizes the procedures available for the separation of milk proteins. Before discussing the details of the processes shown in this diagram, it is necessary to set
out some general guidelines to food technologists who wish to develop strategies for extraction of a dairy protein or a group of dairy proteins.

At each stage of the extraction process, the preservation of desirable qualities (i.e., functional, biological, and nutritional) must be taken into account when choosing technologies and the physicochemical parameters to be used. Particular attention must be paid to successive heat treatments, the effects of which are cumulative. Like most liquid foods, milk and its derivatives are very favorable media for spoilage microorganisms. Consequently, pretreatments and temperature–time parameters and residence time temperature (Jeanet et al., 2008b) must be chosen in order to control microbial growth.

Each separation and fractionation step generates at least one coproduct; for environmental reasons, and because of their potential value, the coproducts must be considered not only as by-products, but also as value-added components of milk. Thus, all extraction procedures must be envisaged in an integrated technological concept that utilizes all of the products and effluents generated.

### 1.2.3 Pretreatment of milk

Milk collected by the dairy industry contains lipids (≈40 g/L) organized in fat globules. Most extraction procedures for milk proteins use skim milk as the starting material. Whole milk is therefore centrifuged in a separator comprising conical discs and running at 5000 rpm at around 50°C. The separated cream generally represents 10% of the volume of the entering whole milk. Fat separation is never perfect, and the skim milk thus obtained still
contains around 0.5 g/L fat, which can considerably influence the effectiveness of down-
stream processes and the resulting protein products.

In developed countries, milk is normally contaminated by common mesophilic and
psychrotrophic microflora and rarely by pathogenic microorganisms. To minimize possible
health hazards and to control bacterial growth during milk processing, moderate heat treat-
ments (at 63°C for 30 minutes or pasteurization at 72°C for 15 seconds) are applied to
skim milk before further processing. The consequences of this heat treatment are numerous
and significant: it decreases the pH, shifts the delicate protein–calcium phosphate equilib-
rium, causes changes in the micellar structure of casein, which in turn affects its hydration
and zeta potential (Fox, 1982), and initiates the Maillard reaction, which permanently
modifies the functional and nutritional properties of the whey proteins (Maubois et al.,
1995). An interesting recent development in the removal of microorganisms from skim
milk is the use of membrane MF technology. Following the recommendations of Sandblom
(1974) and Meersohn (1989), skim milk is microfiltered through a ceramic membrane
(average pore size of 1.4 µm) at a temperature between 20 and 55°C. The average decimal
reduction observed between the inlet milk and microfiltered milk is 2.6, corresponding to
a reduction of the contaminating microorganisms of 99.5%.

1.2.3.1 Isolation of whole proteins

There are two major methods to produce dairy proteins: coprecipitation techniques and
ultrafiltration technology. Coprecipitation involves the application of high heat during the
precipitation process to cross-link the two major proteins (caseins and whey proteins), but
this also results in denaturation of whey proteins. Calcium chloride or acid is also injected
through a spray that is countercurrent to the direction of milk flow to provide full mixing.
The mixture is transformed into curd in a holding tube (20–25 seconds). The curd is sepa-
rated from the whey, and the coprecipitate is washed and pressed. At optimal process condi-
tions, it is possible to recover 95–97% of the milk proteins.

There are three basic varieties of coprecipitates, each having different amounts of
calcium: low calcium coprecipitate (0.1–0.5% Ca), medium calcium coprecipitate (1–1.5%
Ca) and high calcium coprecipitate (2.5–3.5% Ca). These coprecipitates can then be dried
and used as ingredients. The nutritional quality of coprecipitates is better than that of
caseinates, but functionality of coprecipitates is limited to applications where denatured
whey proteins are needed, such as in bakery products. To address this limitation, New
Zealand Milk Products Inc. patented a process for the production of total MPIs in 1983
that has since been improved (Mistry, 2002). The process involves the coprecipitation
of caseins and whey proteins using a series of pH adjustments to prevent the heat
denaturation of whey proteins. A modification of this process that involves ultrafiltration
and diafiltration has also been patented. An ultrafiltration process was developed for the
production of high milk protein powders (MPC/MPI) for applications in cheese and yogurt
making (Fox, 1982; Mistry, 2002). This process was developed using ultrafiltration and
diafiltration of skim milk without pH adjustment to concentrate the proteins, followed by
spray drying.

1.2.3.2 Isolation of whole casein

There are three principal ways available for the production of whole casein on an industrial
scale, that is, isoelectric precipitation, rennet coagulation, and MF. Acid casein is produced
by the use of hydrochloric or sulfuric acid or by lactic acid produced by bacteria. Sufficient acid is added to reduce the pH of the milk to 4.6 and the mix is diluted with four parts water with thorough mixing. After a short holding period in a vat, the whey is drained off. The curd is washed twice with cold water, pressed and milled. Acid casein may also be produced by inoculating skim milk with acid-producing bacteria and incubating it at 20–30°C until the acidity reaches 0.64%. The curd is stirred and heated to 50–65°C. The whey is then drained and the curd washed twice with cold water and pressed for 10–15 hours. It is then milled and ready for drying. Rennet casein is made by adding sufficient rennet and calcium chloride to skim milk to cause it to clot in 20–30 minutes. Stirring is commenced 2–5 minutes after coagulation has started. The temperature is raised to 55–70°C, and the curd is cooked for 30 minutes. The whey is then drained off. Acid or rennet whey may be dried in a cabinet, tunnel, or spray dryer to a moisture content of 4%. The dried casein is milled and screened to an appropriate particle size. Casein is used in the manufacture of paint and plastics and for paper coating. It is also used in coffee/tea whiteners, whipping powders, and imitation milks (Maubois and Ollivier, 1997).

The most promising technology for the selective separation of casein micelles is undoubtedly membrane MF. When whole or skim milk is circulated through a MF membrane with a pore size diameter of 0.1–0.2 µm, a microfiltrate is obtained with a composition close to that of sweet whey. Moreover, it is crystal clear and can be sterile if the downstream equipment prevents recontamination. The retentate is an enriched solution of native and micellar casein, that is, MCC (Fauquant et al., 1988). Diafiltration against water allows its purification into micellar casein isolate (MCI), and it is easily concentrated again by MF and then spray-dried (Pierre et al., 1992; Schuck et al., 1994b). MCI has excellent rennet-coagulating abilities. The coagulation time of a 3% MCI solution is reduced by 53% compared with that of raw milk, and gel firmness at 30 minutes is increased by more than 50% (Pierre et al., 1992). MCI and its coproduct, the WPI obtained by submitting the microfiltrate to a subsequent ultrafiltration step, are excellent starting substrates for further fractionation and isolation of milk proteins.

1.2.3.3 Fractionation of whole casein

There is considerable interest in developing technologies for the fractionation of whole casein into individual components (αs1, αs2, β, and κ) on an industrial scale. These fractions can be potentially used in bovine milk-based infant formulas and for the preparation of biologically active peptides and specific additives. Most published studies have focused on isolation of β-casein, the main component of human casein, which contains numerous peptide sequences with physiological activities, such as the well-known β-casomorphin. The growing commercial interest in the production of functional peptide fragments of αs1- and κ-caseins will probably lead to future developments in the fractionation of these proteins, either from the coproduct resulting from fractionation of β-casein or from the native casein micelles dissociated by the combined action of pH, NaCl, and sodium citrate, as proposed by Pouliot et al. (1994).

1.2.3.4 Whey protein separation

There are several industrial methods suitable for the production of various WPCs and WPIs. The interest in whey processing is a result of two factors. One is a worldwide shortage of high-quality animal proteins that whey proteins may alleviate, and the other is the problem
with the disposal of whey. The high biological oxygen demand of whey makes this cheese
by-product a pollutant so that it is more desirable to process it than to dump it.

In addition to traditional methods, such as evaporation and drying, modern methods
used in industrial whey processing include ultrafiltration, MF, reverse osmosis (hyperfiltration)
and demineralization (electrodialysis and ion exchange). The most commonly used
membrane method in dairying is ultrafiltration. Its industrial application was aided by the
introduction of cross-flow instead of dead-end filtration and the invention of asymmetric
membranes (Carić, 1993). During the ultrafiltration of whey, low molecular weight com-
pounds, such as lactose, minerals, nonprotein nitrogen, and vitamins, are separated in the
permeate, whereas proteins are concentrated in the retentate. This permits a WPC to be
obtained with 20–60% protein in total solids and low quantities of lactose and mineral
matter. Permeate, a by-product of this processing, is used for producing lactose, alcohol,
single-cell protein, yeast, galactose, glucose, cattle feed, and various pharmaceuticals.

Further increases in protein content (up to 98%) may be achieved by adding water to
the feed. This procedure is called diafiltration. The best moment to start diafiltration is
when the optimal total solids content has been reached and at a point where the ultrafiltra-
tion flux is still relatively high.

Sweet whey is first subjected to clarification (removal of casein fine particles, fat separa-
tion, and pasteurization). After pasteurization, the whey is cooled to 60–65°C and held at
this temperature for 30–60 minutes before cooling to 50°C for ultrafiltration. This heat-
and-hold treatment has the function of stabilizing the calcium phosphate complex, thus
reducing the fouling of the membranes during ultrafiltration. Further reduction of other
minerals in WPC is achieved by adjusting the pH of the whey to pH 5.7–6.0 with HCl.
The solubility of calcium is increased with decreasing pH, thus resulting in a greater
proportion of calcium in the permeate. After ultrafiltration, the retentate is pasteurized,
evaporated (or not, depending on the viscosity and protein content), and dried.

1.2.3.5 Fractionation of whey proteins

The main proteins found in WPCs and isolates are: β-Lg, α-La, glycomacropeptides, BSA,
Igs, Lf, and lactoperoxidase. Each of these proteins or groups of proteins has been proven
or believed to have unique functional, nutritional, or nutraceutical properties. Some putative
nutraceutical activities include digestive function (β-Lg and glycomacropeptide), anticar-
cinogenic properties (α-La), antimicrobial activity (Lf and lactoperoxidase) and passive
immunity (Igs). There are also nutritional considerations. It is known that α-La binds
minerals, specifically calcium, magnesium, zinc, and cobalt. By being bound to a protein,
these minerals are more readily delivered for absorption in the human body. The lack of
β-Lg in human milk suggests that bovine whey protein products rich in α-La and low in
β-Lg would be more appropriate for infant formulae.

There is a considerable interest in developing technologies for the fractionation of whey
proteins into α-La and β-Lg on an industrial scale (Maubois and Ollivier, 1997). A number
of methods have been developed (Slack et al., 1986; Maubois et al., 1987; Pearce, 1987)
with commercial scale potential to fractionate the major whey protein components, β-Lg
and α-La, and to produce WPCs enriched in these fractions. These methods depend on
either mild heat treatments of a whey concentrate or a clarified whey under controlled pH
and ionic conditions, or on demineralization of whey concentrate under controlled pH
conditions. These treatments are used to achieve selective reversible precipitation of
α-La- or β-Lg-enriched fractions and the separation of the precipitate from β-Lg- or
α-La enriched solutions. The precipitate is resolubilized by the addition of water and pH adjustment and then dried, while the soluble protein is further concentrated by ultrafiltration/diafiltration prior to drying.

1.3 DRYING PRINCIPLES

Drying is defined as the removal of a liquid, usually water, from a product by evaporation, leaving the solids in an essentially dry state. A number of different drying processes are in use in the dairy, food, chemical, and pharmaceutical industries, such as:

- spray drying;
- fluid bed drying;
- roller drying;
- freeze-drying;
- microwave drying; and
- superheated steam drying.

Due to considerations of drying economics and final product quality, the only processes of significance in milk protein powder manufacture are spray drying, fluid bed drying (the two most often in combination), and roller drying, although the latter is in only limited use nowadays. Only these three drying processes will be discussed here.

1.3.1 Roller drying

In roller drying, a preconcentrated product is applied as a thin film on the outer surface of an internally heated rotating metal drum (Refstrup, 2003). A vapor hood and exhaust system are placed above the drum. The milk film is scraped off the drum surface as a sheet of dry product by stationary knives located opposite the point of milk concentrate application. The product sheet or flakes fall into an auger trough, which partly disintegrates it and conveys it to a pneumatic cooling and conveying system, often with integrated milling, and thence to storage and packaging.

1.3.1.1 Types of drum driers

Several types of drum dryer exist. They can be characterized by the combination of the number of drums (single or double) or the method of product application (sump between two closely positioned drums, spray with nozzles, or immersed applicator roll system).

The main process parameters affecting the plant capacity and product properties are:

- Drum surface temperature: Saturated steam (at up to 0.5-MPa pressure, corresponding to about 150°C) is used as heating medium.
- Feed temperature: This may vary from about 10–80°C depending on the type of product. The higher the feed temperature, the greater is the plant capacity.
- Feed solids content: A total solids content of up to 45% is usually used. The higher the solids content, the faster is the product drying rate.
- Drum rotation speed: The time of exposure to the hot drum surface, and hence the final moisture content, is controlled by the rate of rotation of the drum. This is because, for