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PRODUCTION, FUNCTIONAL PROPERTIES AND UTILIZATION OF MILK PROTEIN PRODUCTS

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1. INTRODUCTION

Bovine milk contains ~ 13% solids which include fat, lactose, protein, and organic and inorganic salts. Normal milk contains ~ 3·5 g total protein per 100 ml which falls into two main categories based on solubility at pH 4·6 at > ~ 8°C. Under these conditions ~ 80% of the total nitrogen precipitates (this fraction is referred to as casein), while 20% remains soluble in the serum or whey; ~ 15% being whey proteins with the remainder being non-protein nitrogeneous components. As discussed in Chapters 2–6, both the casein and non-casein fractions are heterogeneous; casein includes four principal primary proteins (gene products), α_{s1}-, α_{s2}-, β-, κ- and several minor proteins, while the non-casein fraction includes β-lactoglobulin, α-lactalbumin, blood serum albumin, immunoglobulins, casein-derived proteose peptones, several minor proteins, including lactotransferrin, and several enzymes. The characteristics of the caseins and whey proteins differ very significantly (Table 1):

(1) The caseins are insoluble at their isoelectric points (~ pH 4·6) at temperatures > ~ 8°C. At very low ionic strength, most of the whey proteins are also insoluble at their isoelectric points (~ pH 5) but they are soluble in this pH range in the ionic environment of milk.
(2) Coagulation of the caseins can be induced by limited proteolysis using crude proteinase preparations, known as rennets, but the whey proteins remain soluble.
(3) Caseins are extremely heat-stable proteins while the whey proteins are heat labile: sodium caseinate dissolved in water does not coagulate in 60 min at 140°C, while the whey proteins are dentured on heating at temperatures > 70°C. At its normal pH (~ 6·7), milk may be heated at 140°C for 20 min before coagulation occurs; however, on heating milk at > ~ 72°C, whey proteins become denatured and interact with casein to form a complex.
(4) In milk, the caseins occur as large aggregates, micelles, which can be separ-

TABLE 1
Principal Differences between Casein and Whey Proteins

Characteristic	*Casein*	*Whey*
Solubility at pH 4·6	No	Yes
Rennet coagulation	Yes	No
Heat stability	High	Low
Particle size	Large	Small
	(micelles; mol.wt $\sim 10^8$)	(molecules; mol.wt $\sim 1{\cdot}5$–$7{\cdot}0 \times 10^4$)

ated from the molecularly dispersed whey proteins by ultracentrifugation (e.g. 100 000 g for 1 h).

Some of these differences between caseins and whey proteins are exploited in industrial methods for casein and whey protein isolation; however, caseins and whey proteins can also be isolated together in various high-protein products, referred to as co-precipitates. Because of the heterogeneity of both protein systems, methods with industrial scale-up posssibilities are now being developed to effect fractionation to individual proteins.

Because of their source and their nutritional value, dehydrated milk protein-enriched products are 'high esteem' food ingredients. As well as contributing to the nutritional status of foods, the physico-chemical and functional properties of these protein-enriched products are exploited to modify or enhance the textural and rheological characteristics of foods. These proteins bind and emulsify fat, bind and entrap water, and entrap and stabilize air in food products, thus contributing to product stability and sensory appeal.

This chapter will provide an overview of methods for the production of dehydrated milk protein-enriched products, the functional properties of these products and their applications in foods.

2. PRODUCTION OF MILK PROTEIN PRODUCTS

2.1. Production of Caseins

Casein has been produced commercially for at least 70 years. Initially, casein was used for industrial purposes, e.g. glues, paper glazing and synthetic fibres. It was not until the 1960s that isolated casein became an important food protein, due mainly to pioneering work in Australia and New Zealand. Today, casein, produced by acid or rennet coagulation, is one of the principal functional food proteins with an annual world production of $\sim 250\,000$ tonnes. It has some rather unique properties and cannot be replaced by other proteins in certain food applications. Methods for the manufacture of casein and caseinates have been reviewed by Muller (1971, 1982); Mulvihill (1989) and Fox and Mulvihill (1990).

The first step in the isolation of the casein fraction from milk is removal of fat by centrifugation to yield a skim milk from which the casein is isolated after destabilizing it and rendering it insoluble. The use of skim milk ensures that the fat

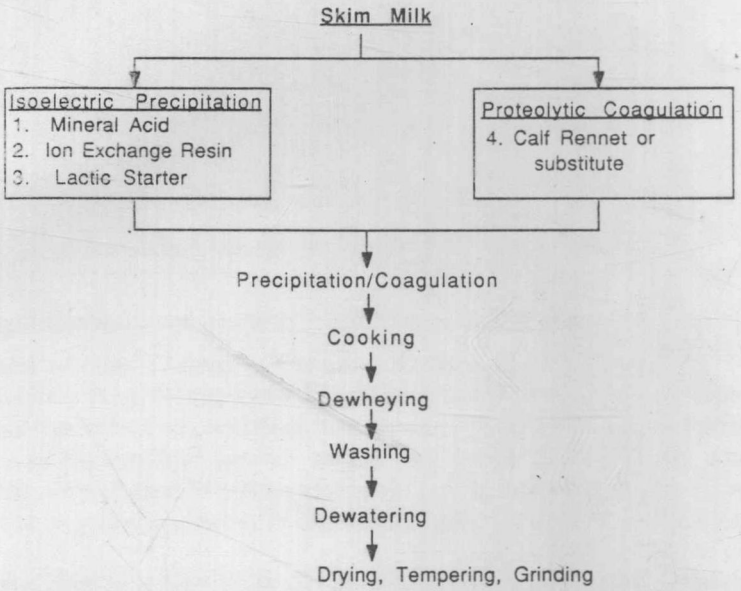

Fig. 1. Casein manufacture.

content of the casein is low enough to minimize flavour defects arising from deterioration of lipids in the dried casein products. Following destabilization, the insoluble casein is separated from the soluble whey proteins, lactose and salts, washed to remove residual soluble solids and then dried (Fig. 1).

2.1.1. Destabilization/Precipitation

(a) In the manufacture of mineral acid casein, precipitation is accomplished by spraying dilute (1–2 M) mineral acid, usually HCl, under pressure into milk (preheated to 25–30°C) flowing in the opposite direction to give a precipitation pH of ~4·6. Steam is then injected to heat the acidified milk to the required precipitation temperature (~ 50°C) and a holding or acidulation tube is used to ensure complete coagulation and agglomeration of the curd prior to separation of the curd and whey (Fig. 2).

(b) The pH of skim milk can also be reduced to the isoelectric point of casein by mixing skim milk at < 10°C with a cation exchange resin in the hydrogen form in a reaction column; this replaces cations in the milk by H^+ to give a pH of ~2·2. The deionized, acidified milk is then mixed with untreated milk to give the final desired precipitation pH of ~4·6. The mixture is then heated to the coagulation temperature by direct steam injection (Fig. 2).

(c) Precipitation in the manufacture of lactic casein is accomplished by inoculating pasteurized skim milk with a mixed or multiple defined-strain starter and incubating at 22–26°C. During an incubation period of 14–16 h, the starter slowly ferments some of the lactose to lactic acid and a casein gel network or coagulum, with good water holding capacity, is formed as the pH of the milk

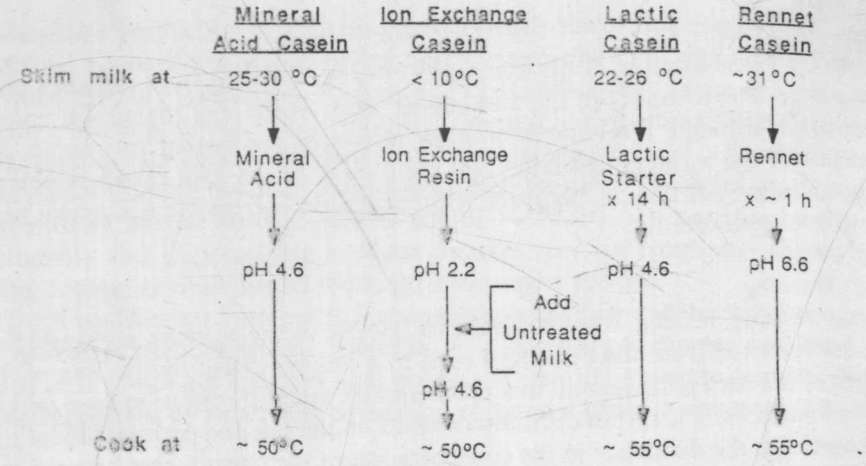

Fig. 2. Casein precipitation conditions.

fails slowly under quiescent conditions to the isoelectric pH of the casein. Following coagulation, the coagulum is pumped from the coagulation vats and cooked by direct steam injection. To permit the curd particles to agglomerate and to initiate syneresis, a period of contact with whey, termed acidulation, either in a holding pipe or vat, is allowed prior to curd and whey separation (Fig. 2).

(d) Any of a number of proteinases can coagulate milk at its natural pH (~6·7) in a two-stage process: the first stage involves the specific hydrolysis of κ-casein to yield para-κ-casein and (glyco)macropeptides, while the second stage involves coagulation of the rennet-altered casein micelles by Ca^{2+} at temperatures above 20°C. When a coagulum of this nature is formed from skim milk, it can be further processed to yield rennet casein in a manner similar to that used for the manufacture of lactic casein following quiescent acid coagulation. Rennet casein has a high ash content, especially colloidal calcium phosphate (CCP), calcium and phosphate. The proteinases traditionally used, referred to as rennets, are crude preparations of gastric proteinases prepared from calf vells. However, the supply of calf rennet has been inadequate for many years and rennet substitutes are now widely used. The primary and secondary phases of rennet coagulation, including the mechanism of gel assembly and the factors influencing gel strength, are now well understood (see Chapter 14). In the traditional method for rennet casein manufacture, skim milk at pH ~ 6·7, is 'set' with rennet (1 : 4500) in large jacketed vats at ~31°C, in a manner similar to that practised in cheesemaking. When coagulation has progressed to the desired stage, the gel is pumped from the coagulation vat to a cooking pipe where steam is injected to raise the temperature to 50–55°C for ~45 s before separation of curds and whey (Fig. 2).

2.1.2. Dewheying

Following destabilization of the casein, the curd is separated from the whey prior to washing. The efficiency of the 'dewheying' step, which is of the utmost importance in determining the volume of whey recovered for further processing, the efficiency of the washing operation and the quality of the final casein produced, depends on the pH and temperature of precipitation and on the equipment used to achieve separation.

2.1.3. Washing

During washing, residual whey constituents (lactose, whey proteins, salts) and free acid are removed from the dewheyed curd to a limited extent by washing of the surface of the curd particles and to a much greater extent by diffusion from within the curd particles. The rate of diffusion depends on the size and permeability of the curd particles, the difference in the concentration of the constituents between the interior of the particles and the surrounding wash water and on the amount, temperature and movement of the wash water.

Washing systems used include multi-stage counter-current systems and counter-current tower washing systems in which the curd falls through an ascending column of water.

It is normal to use a gradient of wash water temperatures during the washing operation. A typical temperature profile for washing acid curd in a four-stage washing system is 55, 65, 75 and 35°C for the first to the fourth stage, respectively.

2.1.4. Dewatering

When washing is complete, casein curd is mechanically dewatered to produce a curd of minimum moisture content to minimize the quantity of water to be evaporated and thus minimize the energy required during the subsequent thermal drying operation. The properties of the casein curd following washing should be such as to allow for maximum dewatering under the conditions of operation of the dewatering machine while at the same time maintaining the curd in a suitable condition for subsequent drying. Mechanical dewatering devices include roller and screw presses and decanting centrifuges.

2.1.5. Drying, Tempering and Grinding

To produce a stable, long-life casein that meets the internationally recognized compositional standards for edible-grade product, the casein curd is dried to $< 12\%$ moisture in any one of a variety of drier types. Traditional driers used are of a semi-fluidized, vibrating type in which casein curd passes along vibrating perforated stainless steel conveyors while warm air is forced up through the perforations, partially fluidizing the curd as it is dried.

Pneumatic ring driers, which consist essentially of a large, stainless steel, ring-shaped duct through which high-velocity, heated air and moist, disintegrated casein curd are circulated continuously, are now widely used to dry casein.

A drying technique, referred to as 'attrition drying', based on the principle of grinding and drying in a single operation, is also widely used in casein plants since

it allows the production of a casein product closely resembling spray dried casein. The drier consists of a fast-revolving, multi-chambered rotor and a stator with a serrated surface. Turbulence, vortices and cavitation effects in the drier result in highly efficient grinding, which pulverizes the curd into very small particles with a large total surface area. These particles are simultaneously dried in a hot air stream that passes through the drier concurrently with the curd. The dried casein is very fine with an overall average particle size of $\sim 100\,\mu m$. The particles have good wettability and dispersability in water because they are irregularly shaped and many contain cavities due to the rapid evaporative process.

Dried casein is relatively hot as it emerges from the drier and the moisture content of individual particles varies. Therefore, it is necessary to temper and blend the dried curd to achieve a cooled final product of uniform moisture content. This is usually achieved by pneumatic circulation of the curd between a number of holding bins.

Following drying, tempering and blending, the casein is ground in roller or pin-disc mills to produce the small-sized particles required by users of casein. Milled material is separated on screens to products of desired particle-size range and oversized material is re-cycled for further milling.

2.2. Production of Caseinates

Acid caseins are insoluble in water but will dissolve in alkali under suitable conditions to yield water soluble caseinates that may be spray or roller dried.

2.2.1. Sodium Caseinate

Sodium caseinate, usually prepared by solubilizing acid casein with NaOH, is the water-soluble casein most commonly used in foods.

The steps involved in its manufacture (outlined in Fig. 3) are as follows:

(1) Casein curd from a dewatering device ($\sim 45\%$ solids) is minced to disintegrate the curd which is then mixed with water at 40°C to give a solids content of $\sim 25\%$, before passing it through a colloid mill.

(2) NaOH (2·5 M) is pumped into the casein slurry, emerging from the mill at < 45°C and with the consistency of 'toothpaste', to give a final caseinate pH of 6·6 to 6·8. The NaOH and slurry must be efficiently mixed with a mixer capable of coping with the high viscosity.

(3) The mixture is transferred to a vat where solubilization occurs as the mixture is vigorously agitated and heated. The slurry is recirculated and/or transferred by pump to a second vat where solubilization is completed as the solution temperature is raised to ~ 75°C. An in-line pH meter is used to indicate whether the correct volume of NaOH solution has been added to the curd and to regulate the addition.

(4) The caseinate solution is pumped to a balance tank through a heat exchanger in which the temperature is increased to ~ 95°C. A second in-line pH meter is used to control further addition of NaOH, if necessary, to give a caseinate of the desired pH.

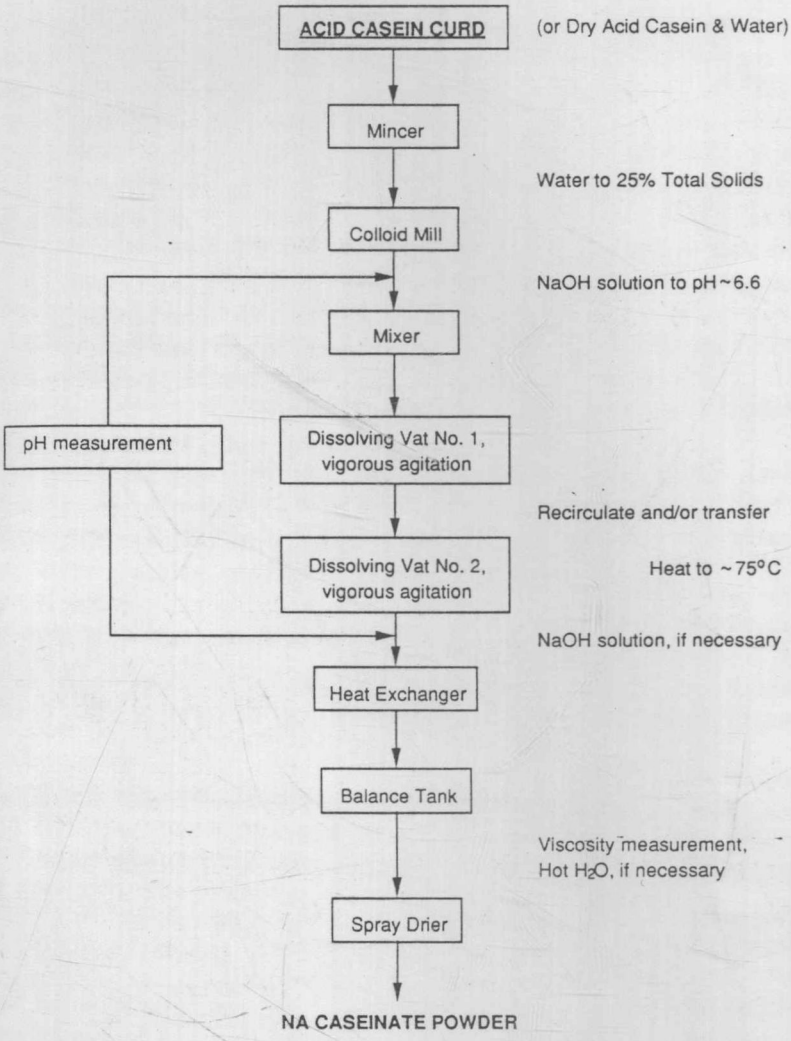

Fig. 3. Sodium caseinate manufacture.

(5) The solution is pumped from the balance tank to the spray drier via an in-line viscometer which regulates hot water addition to control viscosity and ensure efficient atomization of the solution in the drier.

During caseinate production, care must be taken to minimize: (a) the time for which the caseinate solution is held at high temperatures, since brown colouration may occur due to reactions between the protein and residual lactose; (b) the time for which the casein is exposed to high pH during dissolving, as this may lead to the production of lysinoalanine and the development of off-flavours.

2.2.2. Other Caseinates

Other methods used to produce different caseinate types include (Fig. 4):

(1) Production of roller-dried sodium caseinate by feeding a mixture of curd (50–65% moisture) and an alkaline sodium salt (Na_2CO_3 or $NaHCO_3$) onto the drying drum of a roller-drier.

(2) Production of granular sodium caseinate by lowering the moisture content of acid casein curd to < 40%, reacting the curd with Na_2CO_3, with agitation, for up to 60 min and drying the resultant caseinate in a pneumtic ring drier or a fluidized bed drier. The resulting caseinate has a higher bulk density and improved dispersibility compared to spray- and roller-dried products.

(3) Drying a mixture of acid casein curd (45% dry matter) and Na_2CO_3 in an attrition drier to produce a product that looks like spray-dried sodium caseinate but which has a much higher bulk density.

(4) Conversion of casein to caseinate in the presence of a limited amount of water using extrusion techniques.

(5) Production of ammonium and potassium caseinates in a manner similar to that used for the production of sodium caseinate by substituting NH_4OH or KOH for NaOH.

(6) Production of granular ammonium caseinate by exposing dry acid casein to ammonia (gas) and removing excess ammonia with a stream of air in a fluidized bed degassing system.

(7) Production of citrated caseinate by a method similar to that used for the preparation of spray-dried sodium caseinate by using a mixture of trisodium citrate and tripotassium citrate instead of NaOH.

(8) Production of calcium caseinate by: (1) passing 'soft' casein curd through a mixer to give evenly-sized particles; (2) mixing with water to ~25% total solids; (3) passing the mixture through a colloid mill and adjusting the temperature to give a milled slurry at 35–40°C; (4) mixing the slurry with a metered volume of 10% aqueous $Ca(OH)_2$ slurry to give the desired final pH; (5) agitating and recirculating in a low-temperature conversion tank until conversion is complete (> 10 min); (6) heating the dispersion in a tubular heat exchanger to 70°C and pumping directly to a spray drier.

2.3. Miscellaneous Methods of Casein and Co-precipitate Isolation

In addition to the 'traditional' methods described above, several new alternative methods for the preparation of casein or co-precipitates have been reported, some of which may have commercial potential.

One such method involves precipitation of milk proteins by addition of ethanol to reduce the dielectric constant of the mixture (Hewedi *et al.*, 1985). Addition of an equal volume of 60% (v/v) ethanol to pasteurized skim milk or to skim milk that had been heated at 90°C × 10 min, both adjusted to pH 6·3, caused precipitation of ~82% and ~90% of total nitrogen, respectively.

Another method uses selective solubilization of lactose from nonfat-dry-milk using ethanol; the insoluble residue, which may be regarded a a milk protein

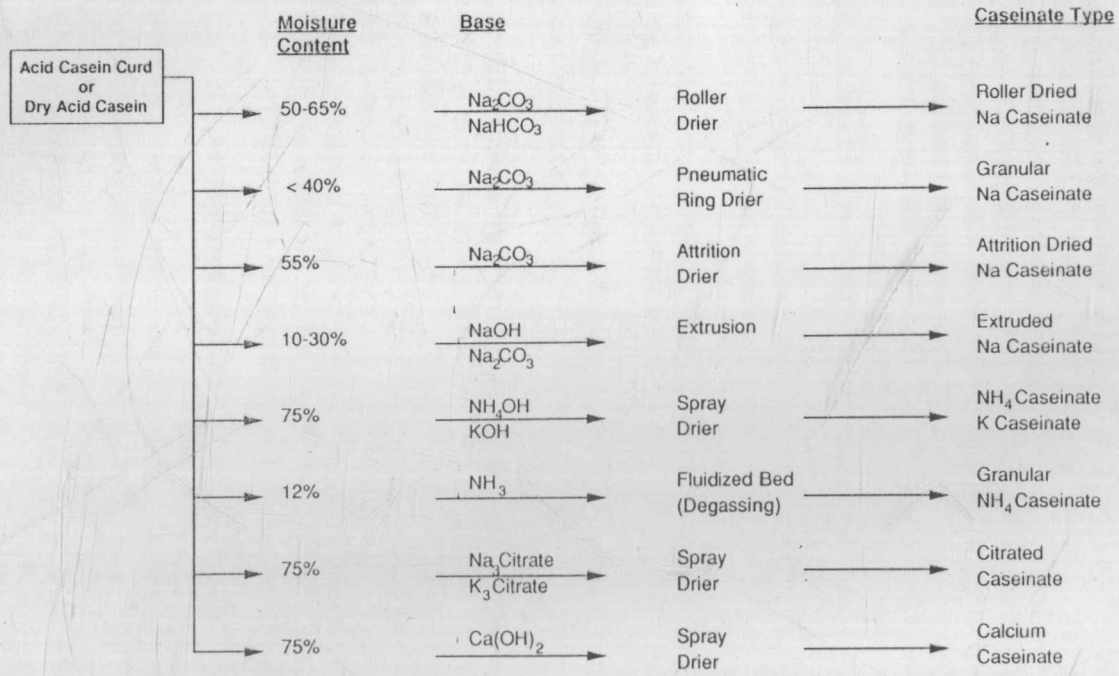

Fig. 4. Methods for the manufacture of different caseinate types.

co-precipitate, had a lactose content of 2–4% using a one-step extraction process under optimum conditions (Hoff *et al.*, 1987).

Ultrafiltration of skim milk to a 4 or 6 volume concentration ratio (VCR = initial volume of milk/volume of retentate) to remove lactose, followed by storage of the retentate at −8°C for 1–4 weeks leads to cryo-destabilization of casein and some whey proteins which are sedimentable by centrifugation at 5000 g for 10 min at 0–5°C (Lonergan, 1983).

Membrane filtration methods for the separation of casein micelles (phosphocaseinate) from all the other constituents of skim milk, including the whey proteins, are reported to have been developed at laboratory level but have not as yet been scaled up to industrial level (Maubois, 1990).

2.4. Industrial Scale Fractionation of Caseins

A number of methods for fractionating casein into β-casein-rich and α_s-/κ-casein-rich fractions on a potentially industrial scale have been developed. These are based on the association characteristics of the caseins which are dependent on ionic strength and/or temperature. At low temperatures, β-casein exists in solution as monomers (Payens & van Markwijk, 1963), a characteristic exploited by Allen *et al.* (1985) to prepare β-casein by renneting calcium caseinate at 4°C; under these conditions, β-casein remains soluble while α_s- and para-κ-caseins coagulate. A method for the isolation of β-casein by microfiltration of calcium caseinate at 5°C was reported by Terre *et al.* (1986). Famelart *et al.* (1989) optimized the same technique to purify β-casein from whole casein at 4°C and pH 4·2–4·6. Murphy and Fox (1990) reported a method for the fractionation of a dilute sodium caseinate solution by ultrafiltration into a β-casein-rich permeate and an α_s-/κ-casein-rich retentate (Fig. 5).

As many peptides derived from caseins have been shown to have biological functions (see Chapter 7), there is growing interest in methods for the production and isolation of these peptides. However, commercial-scale production and isolation methods have not as yet been reported.

2.5. Production of Whey Protein-enriched Products

Whey is the liquid remaining after removal of fat and casein from milk during the manufacture of cheese or acid and rennet casein. There are two principal types of whey; sweet whey (minimum pH 5·6) from the manufacture of cheese or rennet casein, and acid whey (maximum pH 5·1) from the manufacture of acid casein. Average compositons of some whey types are shown in Table 2. Acid whey has a higher mineral/ash content and if the acid has been produced by the action of starter bacteria, the lactose concentration is reduced. Whey proteins represent only 10% of the total solids of whey and on drying wheys the resulting powders have low protein contents. However, a number of processes (Fig. 6) have been developed, and are now being exploited commercially, to recover the whey proteins

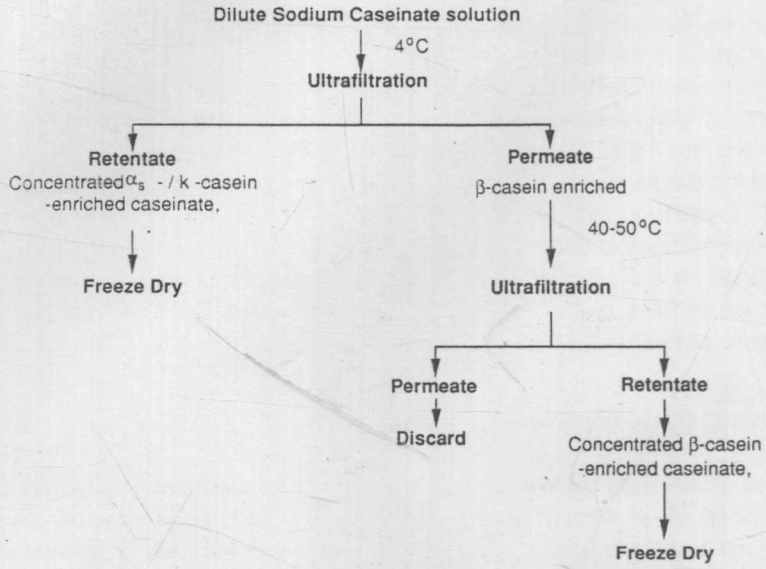

Fig. 5. Method for preparing α_s-/κ- and β-casein enriched caseins (Murphy & Fox, 1990).

in more concentrated forms. These processes have been reviewed by Marshall (1982), Matthews (1984), IDF (1987) and Morr (1989).

Whey and whey protein-enriched solutions are usually pasteurized using minimum temperature and holding times and maintained at low temperature to minimize microbial and physico-chemical deterioration of the proteins and other

TABLE 2
Average Composition and pH of Sweet (Rennet Casein and Cheddar Cheese) and Acid (Lactic and Mineral Acid) Wheys

Component	*Composition (g/litre)*			
	Sweet wheys		*Acid wheys*	
	Rennet casein	*Cheddar cheese*	*Lactic acid casein*	*Mineral acid casein*
Total solids	66·0	67·0	64·0	63·0
Total protein (N × 6·38)	6·6	6·5	6·2	6·1
Non-protein nitrogen (NPN)	0·37	0·27	0·40	0·30
Lactose	52·0	52·0	44·0	47·0
Milk fat	0·20	0·20	0·30	0·30
Minerals (ash)	5·0	5·2	7·5	7·9
Calcium	0·50	0·40	1·6	1·4
Phosphate	1·0	0·50	2·0	2·0
Sodium	0·53	0·50	0·51	0·50
Lactate	—	2·0	6·4	—
pH	6·4	5·9	4·6	4·7

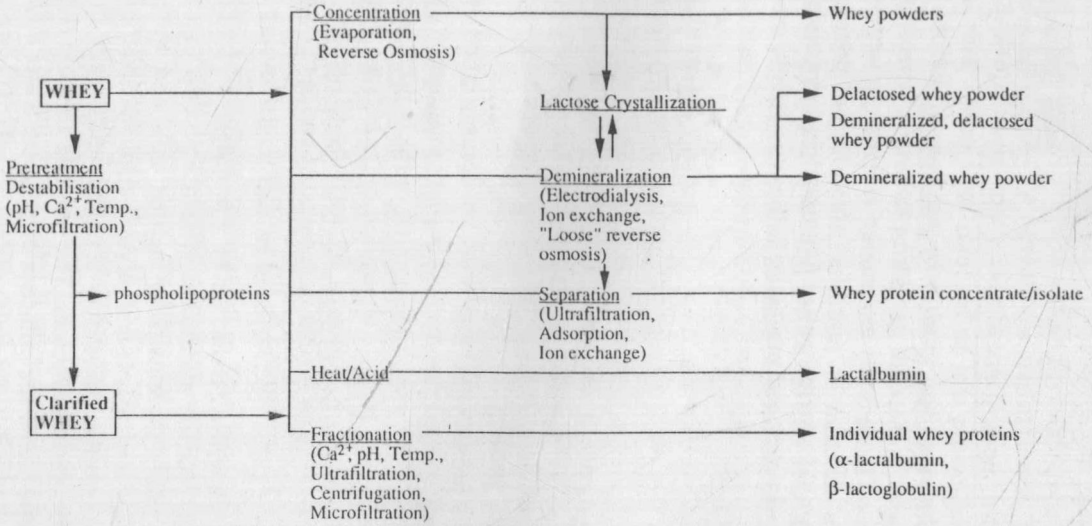

Fig. 6. Industrial isolation of protein products from whey.

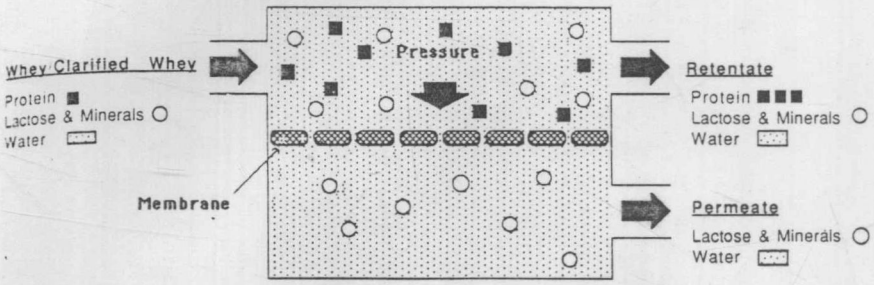

Fig. 7. Production of WPC by ultrafiltration.

whey constituents that would adversely alter functional and organoleptic properties of the resulting protein-enriched products.

2.5.1. Whey Powders/Modified Whey Powders

Whole whey powders containing less than 15% protein are produced by concentrating whey by evaporation or a combination of reverse osmosis and evaporation, followed by spray drying. Demineralization by 'loose' reverse osmosis, electrodialysis or ion-exchange and/or lactose crystallization are used commercially to reduce the lactose and/or mineral concentration of whey and produce modified whey powders such as demineralized and demineralized-delactosed whey powders which contain ~15–35% protein.

Lactose is traditionally crystallized from whey by: concentration of the whey to 58–62% total solids using a multiple-effect falling-film evaporator at a maximum product temperature of ~70°C; controlled cooling of the concentrate and seeding to induce nucleation and crystal growth; separation of the crystals from the mother liquor by decanter centrifugation, followed by washing (if desired) and crystal drying. The mother liquor may be further concentrated and spray dried as a whey protein concentrate powder containing ~30% protein.

2.5.2. Whey Protein Concentrate Production by Ultrafiltration–Diafiltration

Ultrafiltration (UF) is a pressure membrane filtration process that facilitates the selective separation of whey proteins from lactose, salts and water under mild conditions of temperature and pH. It is a physico-chemical separation technique in which a pressurized solution flows over a porous membrane that allows the passage of only relatively small molecules. The retained solution (retentate) flows over the membrane, while, under the influence of pressure, water flows through the membrane, together with the low molecular weight solutes. The protein is retained by the membrane and is concentrated relative to the other solutes in the retentate (Fig. 7). Fat globules and suspended solids are also retained.

The membranes used in UF are asymmetric microporous structures, the effective layers of which appear to contain pores with diameters ranging from 1 to 20 nm. Commonly used membrane configurations include tubular, spiral-wound, plate

and frame and hollow-fibre, with each configuration offering advantages and disadvantages for particular applications. The membranes are manufactured from synthetic polymers (e.g. polysulphone or polyamide). They are characterized by high resistance to high temperatures (up to 100°C), can withstand a wide pH range (1–13) and can be cleaned with agents normally used in the dairy industry (e.g. HNO_3 and NaOH). Although UF is currently the method of choice for the commercial manufacture of WPC of varying protein concentrations, it has several major problems which limit its operational performance. These problems include: high capital and operating costs; membrane fouling, with concomitant loss of permeate flux rate; incomplete removal of low molecular weight solutes unless diafiltration (dilution of retentate with water and repeated UF) is used; cleaning, sanitation and related microbial problems; disposal of large volumes of permeate.

Prior to processing, whey is commonly pre-treated by methods involving pH and/or temperature adjustments, addition of calcium or calcium complexing agents and either quiescent standing, centrifugation or microfiltration to dissolve colloidal calcium phosphate and/or to remove insoluble cheese curd or casein fines, milkfat and calcium lipophosphoprotein complexes (Hayes *et al.*, 1974; Breslau *et al.*, 1975; De Wit & De Boer, 1975; Lee & Merson, 1976; De Wit *et al.*, 1978; Matthews *et al.*, 1978; Muller & Harper, 1979; Maubois *et al.*, 1987).

These pre-treatments increase flux during ultrafiltration, prevent fouling of the membranes and modify the properties of the whey protein concentrates.

The limit for whey concentration by UF on modern plants is ~24% total solids, with a protein/total solids ratio limit of ~0·72 : 1. Difiltration is employed to achieve a higher ratio of protein/total solids (~0·80 : 1) and a total solid content of ~28%.

2.5.3. Production of Whey Protein Isolate (WPI) by Ion Exchange Adsorption

Whey proteins are amphoteric molecules and may be considered as ions. At pH values lower than their isoelectric point (~pH 4·6), whey proteins have a net positive charge and behave as cations which can be adsorbed on cation exchangers. At pH values above their isoelectric point, the proteins have a net negative charge and behave as anions which can be adsorbed on anion exchangers. Media with suitable pore sizes and surface characteristics have been developed specifically for the recovery of proteins from dilute solutions, depending upon the pH of the medium. Two major ion exchange fractionation processes have been commercialized for the manufacture of WPI (Fig. 8).

The 'Vistec' process uses a cellulose-based exchanger in a stirred tank reactor (Burgess & Kelly, 1979; Palmer, 1982). The process involves a series of steps that are performed as a fractionation cycle: (1) whey is adjusted to pH < 4·6 with acid, pumped into a tank reactor and stirred to allow protein adsorption onto the ion exchanger; (2) lactose and other unadsorbed material are filtered off with the water; (3) the resin is resuspended in water and the pH adjusted to > 5·5 with alkali to release the proteins from the ion exchanger; (4) the aqueous solution of proteins is separated from the resin by filtration in the tank reactor, concentrated by ultrafiltration and evaporation, and spray dried as WPI containing ~95% protein.

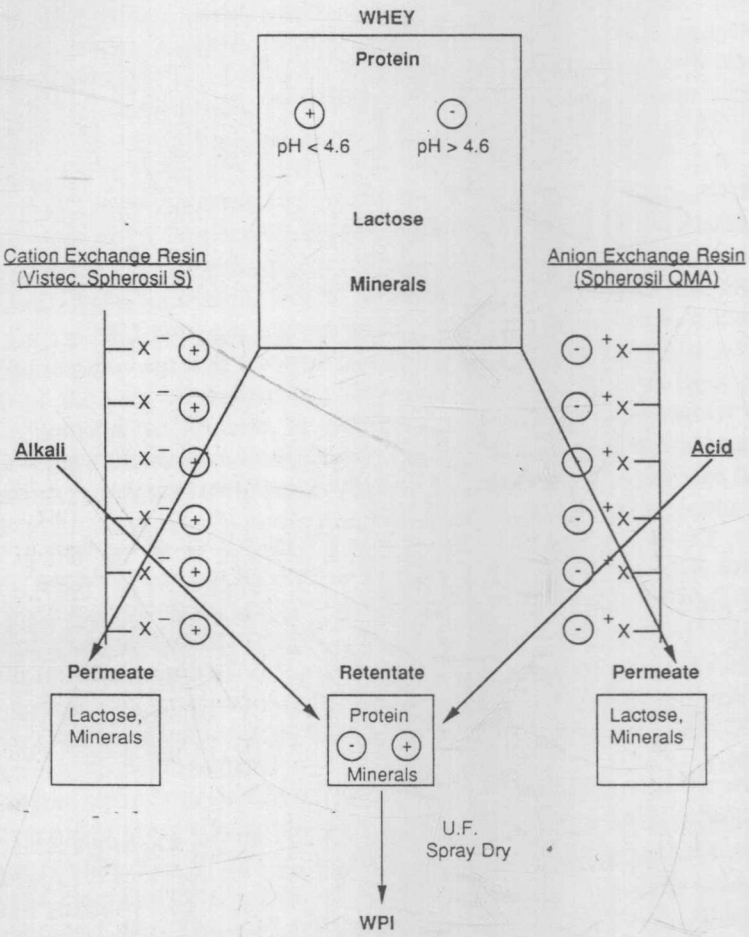

Fig. 8. Production of whey protein isolate (WPI) by ion exchange adsorption.

UF treatment of the protein-rich eluate fraction is essential for purification and concentration of the protein.

The 'Spherosil' processes (Mirabel, 1978; Kaczmarek, 1980) use either cationic Spherosil S or anionic Spherosil QMA ion exchangers, and fractionation is accomplished in fixed-bed column reactors. Acidified whey at pH < 4·6 is applied to the Spherosil S column reactor to allow protein adsorption. After lactose and other unadsorbed solutes have been eluted with water, the pH is raised by addition of alkali to elute adsorbed proteins from the reactor. The protein-rich eluate fraction is concentrated by UF and evaporation and spray dried to produce WPI. Sweet whey at pH > 5·5 is applied to the Spherosil QMA column reactor to permit negatively charged protein molecules to adsorb onto the ion exchanger. After elution of non-protein materials, the proteins are released by lowering the pH with

acid. Released proteins are concentrated and spray dried as WPI, as for the Spherosil S process.

These adsorption processes recover ~85% of the protein under ideal operating conditions. The recovered concentrates are characterized by high protein and low lactose and lipid concentrations and have good functionality. However, several major problems are associated with these ion exchange processes, including: (1) production of large volumes of rinse water, chemical solutions and deproteinized whey which must be processed or disposed of; (2) the need to concentrate and purify the dilute protein-containing eluate by UF, evaporation and drying; (3) the excessive time requirement for conducting each fractionation cycle; (4) microbial contamination of the reactor.

2.5.4. Lactalbumin Production

Whey proteins are globular proteins and are readily denatured on heating. On transformation from their globular conformations to more random structures, sulphydryl and hydrophobic groups are exposed and protein–protein interactions occur. The extent of aggregation and precipitation of the denatured proteins depend on heating temperature and holding time, pH and concentration of calcium. Commercial precipitation conditions depend on whey type and the desired final product characteristics and whey may be preconcentrated and/or dimineralized prior to precipitation (Fig. 9). The precipitated protein, referred to as lactalbumin, may be recovered by settling and decanting, vacuum filtration, self-desludging centrifuges or horizontal solid-bowl decanters. The precipitate may be washed to reduce mineral and lactose contents and dried in spray, roller, ring or fluidized bed driers. Protein yields may be up to 80% of that in the whey, and lactalbumin containing up to 90% protein on a dry weight basis may be recovered, depending on precipitation pH and degree of washing.

2.5.5. Fractionation of Whey Proteins

A number of methods have been developed (Amundson *et al.*, 1982; Slack *et al.*, 1986; Maubois *et al.*, 1987; Pearse, 1987), that may have commercial scale potential, to fractionate the major whey protein components, β-lactoglobulin and α-lactalbumin, and produce whey protein concentrates enriched in these fractions. These methods (Fig. 10) depend on either mild heat treatments of a whey concentrate or a clarified whey under controlled pH and ionic conditions or demineralization of whey concentrate under controlled pH conditions, to effect selective reversible precipitation of α-lactalbumin or β-lactoglobulin enriched fractions and the separation of the precipitate from β-lactoglobulin or α-lactalbumin enriched solutions. The precipitate is resolubilized by water addition and pH adjustment and then dried while the soluble protein is further concentrated by ultrafiltration/diafiltraton prior to drying.

There is also considerable interest in the isolation of biologically-active proteins, such as lactoferrin and lactoperoxidase, and biologically- or functionally-active peptides from whey. Since biologically-active proteins and peptides are reviewed in Chapter 7, they will not be considered further here.