Manufacture of milk protein concentrates and isolates by membrane filtration

Membrane processing emcompasses a range of separation technologies which are widely applied for concentration of dry matter, protein enrichment and isolation or removal of bacteria. Milk protein isolates are usually employed in specialised applications, where superior processing or nutritional functionality are required, for example, in confectionery, sport or medical nutrition

Membrane filtration

Membrane filtration is a widespread processing technology which is used in the dairy industry to physically separate and selectively concentrate milk components (namely, fat globules, caseins, whey proteins, lactose and milk minerals). By influencing the ratio between these components it is possible to obtain a liquid or powdered ingredient with specific composition and hence functionality.

Membrane processing encompasses a range of separation technologies which are widely applied within dairy processing for removal of bacteria and bacterial spores, de-fatting of milk and whey, protein enrichment and isolation, partial demineralisation, concentration of dry matter and recovery of water.

How does the filtration process work?

Membrane separation spectrum as applied in dairy technology

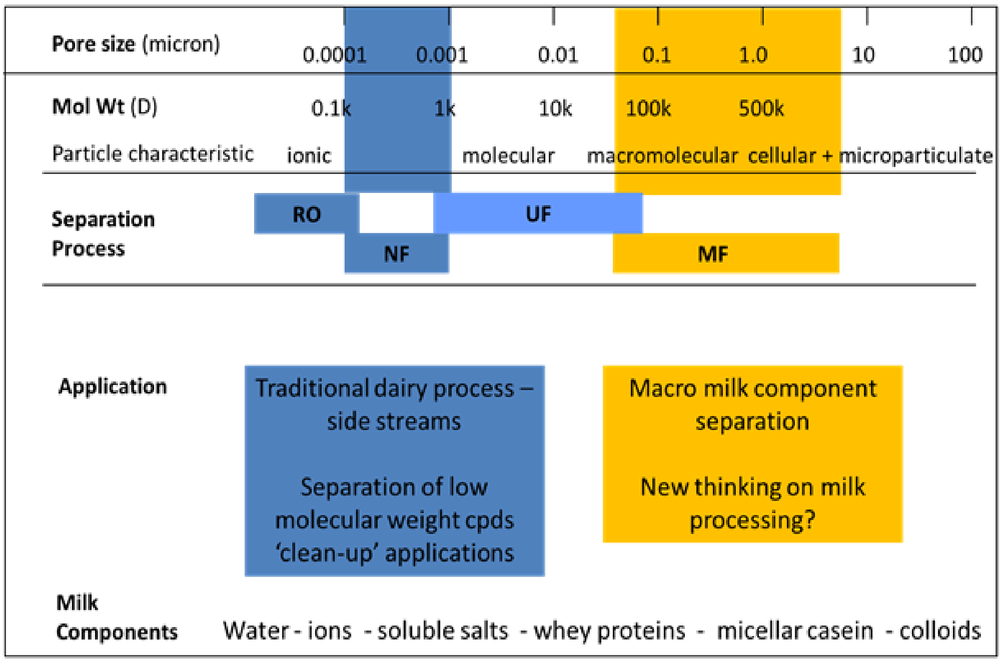

Figure 1: Spectrum of physical separation of milk components using membrane technologies.

The filtration process is pressure driven, where (in cross flow mode) the feed runs parallel to the membrane surface, and permeate is transmitted perpendicularly to the direction of flow. The characteristics of the membrane, design of the processing plant, concentration factors applied, properties of the feed material and its propensity to cause formation of a secondary filtration layer by way of fouling, govern the partition dynamics and performance for a given process. Membrane types used in the dairy industry are distinguished based on their fabrication material and design (e.g. tubular ceramic or spiral wound polymeric) and on their ability to reject components based on specific molecular weight cut offs (MWCO), or nominal pore sizes. Figure 1 illustrates the spectrum of rejection based on membrane selectivity relative to milk components.

Membrane performance

Typical reverse osmosis (RO) membranes show NaCl rejections of about 98% with MWCO of approximately <150 Da. During RO, high pressures (typically >3 MPa) generated within the membrane plant overcome osmotic pressure resistance, forcing water from the retentate to the permeate side of the membrane, thus concentrating the product. A high rejection of milk components is achievable and concentration levels of above 30% dry matter content are attainable, dependent upon the characteristics of the product (osmotic potential, viscosity, fouling potential, pretreatment etc.) and the membrane (pressure limitations, feed spacer configuration etc.).

Nanofiltration (NF), as an evolution of RO, is also a high-pressure filtration process, albeit normally operating in the range of 2-2.5 MPa. Unlike RO, NF membranes typically operate within a MWCO ranging from 150-300 Da; however, MWCO of 500-800 Da are also available for bespoke applications. Nanofiltration also concentrates the total dry matter contents to levels achievable by RO; however, the concentration is offset by a partial depletion or partition of certain ionic species, predominantly monovalent ions Na^+, Cl^- and K^+ during milk concentration. Rejection rates for NaCl of ~ 40-60% are common during NF whereas rejection rates of 98-99% for $MgSO_4$ and lactose are achievable, indicating that some loss of low molecular weight components will also occur during concentration by NF.

Ultrafiltration (UF) is a low-pressure filtration process normally operated at pressures of <1MPa, with operating conditions dependent on plant configuration, number of membranes per housing and the presence of intermediate booster pumps for membranes connected in series. Typically MWCOs for UF range from 1-500 kDa and rejection is driven based on the size of the macromolecules to be separated whereas for milk typically all proteins are rejected by the membrane. It is well accepted that 10 kDa (polyethersulfone PES) UF membranes are the workhorse of the dairy industry, used in the manufacture of various milk protein and whey protein fractions, whereby smaller molecular weight components such as lactose, non-protein nitrogen and soluble minerals are selectively permeated through the membrane as a co-product stream known as milk/whey permeate.

Microfiltration (MF), originally only available in ceramic (aluminum/titanium oxides) membranes, has evolved over time from using uniform transmembrane pressure systems for control of pressure drop (and hence fouling) across the membrane to membrane redesign as a means of promoting gradient permeability – frequently referred to commercially as 'GP' and isoflux™ ceramic membranes. In addition, specifically configured spiral wound polymeric MF membranes are increasingly used for dairy applications. Microfiltration membranes used in the dairy industry are in the range of pore size (0.08-2 µm) and are often used for reducing bacterial numbers, and more recently, for the selective concentration of micellar casein through fractionation of serum proteins and other soluble components.

Diafiltration

An important step during membrane filtration is diafiltration (DF), a process integral in the manufacture of protein concentrates and isolates. During DF, water is added sequentially at different stages within the membrane plant, diluting the concentrated retentate, reducing viscosity, altering fouling dynamics, improving permeate flux and allowing the transmission of residual permeable components. The extent of diafiltration, which in itself is governed by a multitude of product and equipment-based factors determines the final ratio of proteins versus other lower molecular weight solids. In this fact sheet, the use of UF and MF with subsequent DF is addressed as these processes are key to producing milk protein concentrates (MPCs) and isolates (MPIs).

Milk protein concentrates and isolates

Milk proteins are selectively concentrated using UF or MF membranes (Figure 2). The main milk proteins, caseins, are present in a micellar form, and colloidally suspended within a soluble phase containing serum proteins, non-protein nitrogenous compounds, lactose and minerals. Depending upon membrane pore size/MWCO, selective concentration of the protein is achieved. Using the larger pore size membranes typical of MF (with pore sizes of about 0.1-0.2 µm) it is possible to transmit through the membrane a fraction of the serum proteins (65-95% dependent upon equipment design), thereby, creating a retentate stream of micellar casein and a permeate stream containing serum proteins. In this case, the retentate obtained is called micellar casein concentrate/isolate (MCC/MCI). These concentrates have very targeted use as the altered casein to serum protein ratio favours such applications as cheese milk standardisation, yoghurt and structured dairy products, sports nutrition, and medical nutritional products.

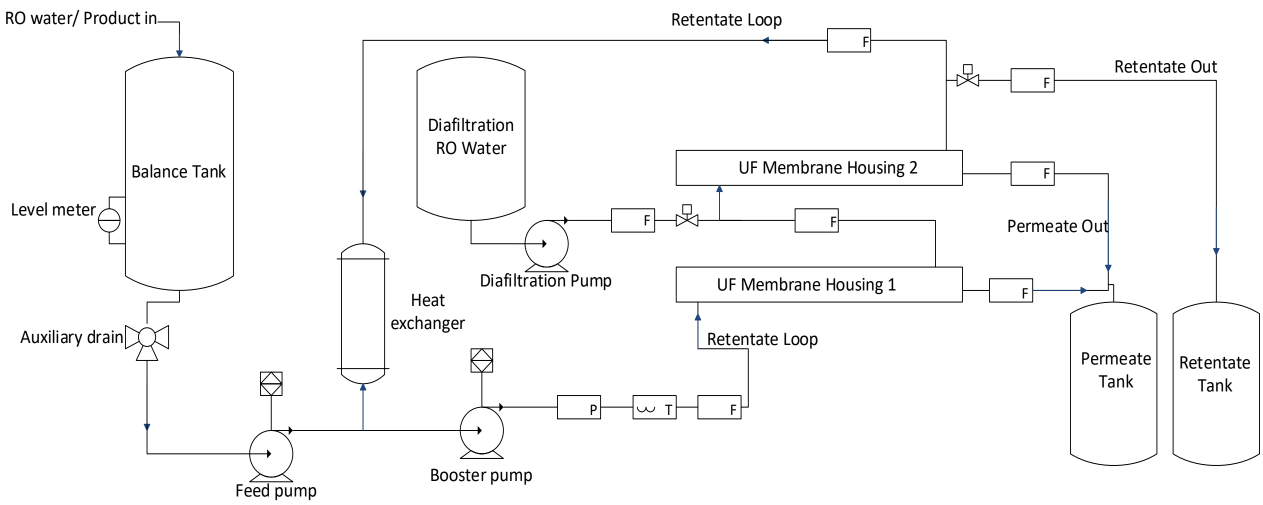

Figure 2. Typical ultrafiltration (UF) plant configuration for Milk Protein Concentrate production including ‘in series’ connected membrane modules and sequential addition of diafiltration water

In general, conventional milk protein concentrates are obtained using UF, coupled with a bespoke DF step. The higher the DF ratio, the greater is the ratio of protein to other solids in the final product. During UF, the ratio of casein to serum proteins in skim milk is maintained, whereas lactose, non-protein nitrogen and soluble minerals permeate through the membrane. It is important to note that the colloidal portion of the minerals in milk are retained in the retentate during concentration, thus changing the ratio between colloidal and serum ions. Milk protein concentrates contain 40% to 87% (w/w) protein in dry matter (PDM) - once the protein value approaches 90% PDM, the ingredients are known as “isolates”. The increasing protein content is associated with a concomitant decrease in soluble phase components (see Table 1).

Table 1. Minimum (%) protein and maximum (%) fat, lactose, ash and moisture in milk protein concentrates and isolates (from American Dairy Products Institute; ADPI). *

Product	Protein (min)	Fat (max)	Lactose % (max)	Ash % (max)	Moisture % (max)
MPC40	39.5	1.25	52.0	10.0	5.0
MPC42	41.5	1.25	51.0	10.0	5.0
MPC56	55.5	1.50	36.0	10.0	5.0
MPC70	69.5	2.50	20.0	10.0	6.0
MPC80	79.5	2.50	9.0	8.0	6.0
MPC85	85.0	2.50	8.0	8.0	6.0
MPI	89.5	2.50	5.0	8.0	6.0

(*) Protein content ≥ 85% is reported on a dry weight basis, all other parameters are reported 'as is'

Applications for milk protein concentrates and isolates

Preparation of MPCs by UF allows for standardisation of product protein content, and utilisation of such concentrates for development of protein-enriched products. The ratio between proteins and minerals affects functional properties, especially solubility, heat stability, and other processing functionalities[1,2,3]. It is also important to stress that the processing history of the concentrates, including thermal pre-treatments, concentration and drying, as well as storage, will affect the functionality, and in particular rehydration characterisitics[4,5.] An indication of thermal history of concentrates is the amount of soluble serum protein present after reconstitution, but this needs to be reported per gram of total protein[6] . As previously mentioned, the extent of diafiltration of the feed during concentration will impact the ratio of colloidal to soluble calcium, and further changes can be obtained by modulating the reconstitution conditions, such as the ionic composition of the dispersant[2]. Spray drying will cause higher aroma intensities such as cooked or cardboard flavours in the reconstituted material when compared to fresh liquid concentrates[7].

Milk protein isolates are usually employed in specialised applications, where superior processing or nutritional functionality are required, for example, in confectionery, sport or medical nutrition. The high protein to lactose ratio present in milk protein isolates makes them excellent ingredients for protein fortified beverages and foods, or for products containing low sugar levels. The high ratio of mcellar casein to serum protein in MF produced micellar casein may be used to standardise milk for cheese manufacture or for the production of casein enriched ingredients. Heat stability of milk protein concentrates, in general, decreases with increasing protein content[3]. However, partial removal of serum proteins during MF may improve stability, particularly in ultra-high temperature (UHT) beverage applications[8]. Technological advances in membrane processing coupled with understanding of compositional changes, facilitates the development of MPC / MPIs with targeted functionality for new applications within the food industry.

References

1. Sikand, V., Tong, P.S., Roy S., Rodriguez-saone, L.E., Murray, B.A. Solubility of commercial milk protein concentrates and milk protein isolates. Journal of Dairy Science, 94:6194-6202 (2011)
2. Crowley, S.V. Desautel, B., Gazi, I., Kelly, A.L., Huppertz, T., O'Mahony, J.A. Rehydration characteristics of milk protein concentrate powders. Journal of food engineering, 149:105-113 (2015).
3. Crowley, S.V., Megemont, M., Gazi, I., Kelly, A.L., Huppertz, T., O'Mahony, J.A. Heat stability of reconstituted milk protein concentrate powders. International Dairy Journal, 37:104-110 (2014).
4. Gazi, I., Huppertz, T. Influence of protein content and storage conditions on the solubility of caseins and whey proteins in milk protein concentrates. International Dairy Journal, 46:22-30 (2015).
5. Eshpari, H., Tong, P.S., Corredig, M. Changes in the physical properties, solubility, and heat stability of milk protein concentrates prepared from partially acidified milk. Journal of Dairy Science, 97:7394-7401 (2014).
6. Sikand, V., Tong, P.S., Walker, J. Impact of protein standardisation of milk powder with lactose or permeate on whey protein nitrogen index and heat classification. Dairy Science and Technology, 88:105-120 (2008).
7. Carter, B., Patel, H., Barbano, D.M., Drake, M.A. The effect of spray drying on the difference in flavor and functional properties of liquid and dried whey proteins, milk proteins, and micellar casein concentrates. Journal of Dairy Science, 101:3900-3909 (2018).
8. Renhe, I.R.T., Corredig, M. Effect of partial whey protein depletion during membrane filtration on thermal stability of milk concentrates. Journal of Dairy Science, on line.