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# Membrane Applications in the Food Industry

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ABSTRACT:Membrane processing offers several advantages to the food industry such as gentle treatment of the product at ambient temperature and thus often a substantial improvement in quality. Low energy consumption, simultaneous fractionation and concentration, demineralization, increased yield, simple plant lay–out and simple operating mechanisms are other advantages. Different aspects of the application of membrane technology in the food industry are discussed in this paper.
KEY WORDS: Ultrafiltration / Reverse Osmosis / Cross Flow Microfiltration / Membrane Technology / Food Applications

The use of membrane technology in the food industry is increasing. Established membrane processes in this field include reverse osmosis (RO), ultrafiltration (UF), microfiltration (MF) and electrodialysis (ED). The application of new membrane processes, such as pervaporation, is under development. In 1988 the annual sale of membranes and membrane modules for the food industry was estimated at about 160 million US $ or about 15 % of the total annual sales, divided as follows: MF 75, UF 55, RO 15 and ED 15 million US $[1].

Most of the microfilters installed so far are run in the dead–end mode. The main applications are found in the beverage industry, where microfiltration is used to achieve sterile filtration and clarification. The use of cross–flow microfiltration is increasing, leading to a better performance and a substantially longer membrane life. In this paper cross–flow applications only will be discussed.

Ultrafiltration often presents a unique separation solution. One example is when ultrafiltration is used for fractionation. In other applications ultrafiltration is an alternative to other separation processes. When used for concentration ultrafiltration sometimes competes with evaporation, for example.

The largest UF membrane area in the food sector is installed in the dairy industry. It has been estimated that about 150,000 $m^2$ were installed by the end of 1988 for the ultrafiltration of milk and whey, the annual growth being about 30% according to Maubois[2]. About 2/3 of the membrane area installed in the dairy industry is used for the treatment of whey and about 1/3 for milk[3].

Reverse osmosis is normally used for the concentration of liquid foods and food process effluents but also in some cases for fractionation purposes, e.g. in the beverage industry in the production of beer with reduced alcohol content.

Partial demineralization can be obtained by using membranes in the intermediate range between UF and RO. High molecular–weight compounds are simultaneously concentrated. A higher degree of demineralization can often be obtained using electrodialysis. In this case, however, the product is not concentrated simultaneously. Most ED plants are installed in the dairy industry.

## SPECIAL CONSIDERATIONS IN FOOD INDUSTRY APPLICATIONS

Membrane processing offers several advantages to the food industry, such as gentle treatment of the product at ambient temperature thus offering a substantial quality improvement. Low energy consumption, simultaneous fractionation and concentration, demineralisation, increased yield, simple plant lay–out and simple operating mechanisms are other advantages. However, this technique also suffers from special problems limiting its use, e.g. fouling, leading to a flux decrease and sometimes a change in separation characteristics. The maximum concentation factor obtained can, in some membrane processes, be limited by viscosity and/or osmotic pressure.

The following factors are of special importance for the application of membrane technology in the food industry:

* Pretreatment of the product. Food products are biological materials and are liable to deteriorate, sometimes very quickly. Therefore, storing, transport, etc. may considerably influence properties which are of inportance not only for product quality but also for separation performance. Product history should be carefully studied in order to guarantee consistent results from day to day.
* Hygienic design and maintenance of the plant
* Cleaning of the plant
* Quality of the water used in the cleaning procedure as well as during start–up.
* Scale–up. For reasons mentioned above it is very important to consider the product history when using laboratory or pilot–plant tests in the design of a production plant. It should also be borne in mind that a laboratory test is normally not sufficient for scaling–up. Flow conditions are, in general, completely different to those in the industrial plant. Tests must be performed in a pilot unit with the same flow conditions as in the commercial plant.

## FOOD APPLICATIONS

Below is a list of the main applications of membrane technology in the food industry[4,5,6,7,8,9]. Some of these as well as some potential applications will be discussed further in this paper.

**Dairy industry**

| | |
|---|---|
| RO processes: | concentration of milk and whey, demineralization of whey |
| ED processes: | demineralization of whey |
| UF processes: | protein standardization, cheese production, whey protein con–centrate production |
| MF processes: | bacteria removal, defatting of whey |

**Other animal protein processing**

| | |
|---|---|
| RO processes: | concentration of hen's egg–white |
| UF processes: | concentration of blood serum proteins, concentration of gelatin, concentration of whole egg |
| MF processes: | prefiltration of gelatin |

**Fruit juice industry**

| | |
|---|---|
| RO processes: | concentration of fruit juice (apple, orange, tomato etc.) |
| UF and MF–processes: | clarification of fruit juice (apple, orange, grape, pear, pineapple, cranberry)<br>concentration of pectin (UF) |

**Wine and beer**

| | |
|---|---|
| RO processes: | concentration of grape must, stabilization of tartrates, concentration of wine, reduction of alcohol content in beer |
| UF processes: | protein stabilization and colour reduction in wine |
| MF processes: | "cold" pasteurization of beer, recovery of tank bottoms<br>clarification of wine |

**Sugar industry**

| | |
|---|---|
| RO processes: | concentration of thin juice |
| UF processes: | purification of raw juice |

**Waste water treatment**

| | |
|---|---|
| RO and UF–processes: | processing of potato fruit juice<br>effluent from wheat starch processing |

## DAIRY APPLICATIONS

### Ultrafiltration

Milk

Milk contains about 12.5% total solids, of which 3.8% is fat, 3.2% protein (2.5% casein and 0.7% whey proteins), 4.8% lactose and 0.7% minerals. Some of the minerals, namely calcium, magnesium, phosphate an citrate, are partly bound to proteins and partly free in solution. The equlibrium between bound and dissolved minerals can be changed, for instance, by changing the pH.

Ultrafiltration of milk is carried out, for example, in the manufacture of cheeses.The membrane area installed for ultrafiltration in cheesemaking has increased rapidly during the 80's and about 18,000 $m^2$were in use by the end of 1987, which is equivalent to about 400,000 tonnes of cheese/year, or 3% of the total world cheese production[10]. The maximum concentration obtained is reported to be 52% TS for whole milk and 39% for skim milk.

In traditional cheesemaking, coagulation occurs after the addition of starter culture and rennet to the cheese milk. The whey proteins are lost in the whey, which is drained off from the curd. By concentrating the milk proteins using ultrafiltration before cheesemaking, this loss can be prevented or reduced as the whey proteins are included in the final product, giving a considerably increased yield.

Intensive work has been, and is being done, on ultrafiltration for the manufacture of fresh, soft, semihard and hard cheeses, e.g. Quarg, Feta cheese, Mozzarella, blue cheese, Cheddar cheese[11,12,13].

So far, the use of ultrafiltration for the production of semihard and hard cheeses is very limited. Cheddar cheese is, however, being successfully made commercially

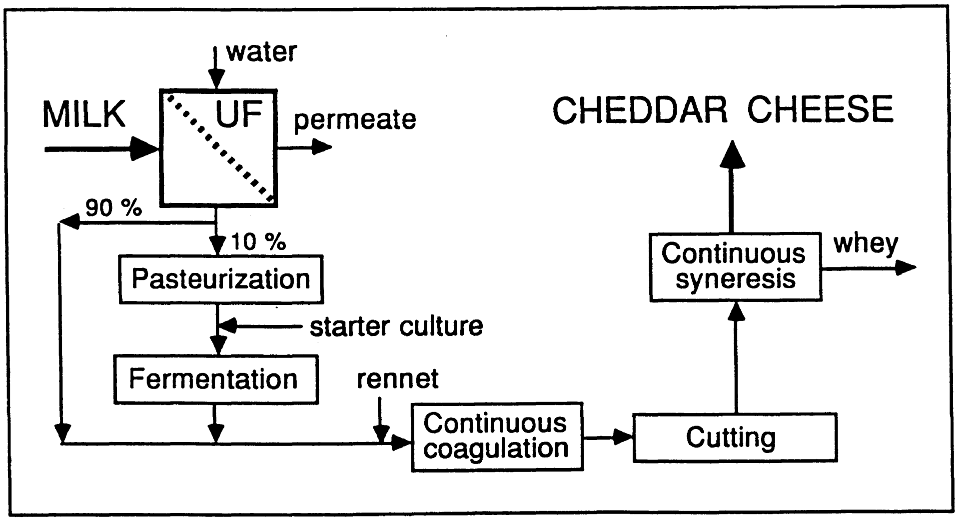


Fig.1. Flow scheme for the APV–SiroCurd process.

from UF retentates by a process developed in Australia. In this process there is a certain whey drainage, which is not the case when fresh and soft cheeses are produced. A flow scheme for the cheddar cheese process is shown in Fig. 1[11].

Traditional process technology must be modified in many cases when UF concentrates are used instead of milk. It is, for instance, very important to carefully adjust the mineral balance in order to obtain the correct rheological properties and taste in the final product. Ultrafiltration at the normal pH of the milk often results in too high a calcium content in the final product, giving off–flavours and unsatisfactory rheological properties.

Today it is possible to predict the performance of an ultrafiltration plant in general, even if the influence of some parameters is not fully understood. The variation in milk composition, temperature history of the milk etc. are such factors.

Whey

Whey contains about 0.7% proteins, 5% lactose, some salts and about 93% water. The whey proteins, having excellent functional properties, can be recovered and concentrated by ultrafiltration. Lactose and salts can be removed simultaneously. Depending on the degree of volume concentration, whey protein concentrates (WPC) with different protein contents can be obtained; the most common types containing 35%, 60% and 80% protein per gram of total solids (TS). In order to obtain a high protein content in the retentate, the retentate is diluted with additional water in the last ultrafiltration stage and then further ultrafiltrated in order to obtain a selective removal of lactose and salts.

Flux rates are affected by pretreatment, temperature, volume reduction factor, pH etc. Typically, flux ranges of 25–50 $l/m^2h$ are obtained with sweet whey. Permeation rates for acid whey are lower than for sweet whey and the UF flux for hydrochloric acid whey at pH 4.1–4.4 is reported to be about 60% of the flux for Cheddar cheese whey in the pH range 5.7 –6.4[14].

Pretreatment

Before ultrafiltration, the whey should be clarified in order to remove fines, etc. It should also be pasteurized in order to inactivate the starter culture, thus preventing a rapid pH drop due to lactic acid formation.

The main fouling agent in the ultrafiltration of whey is calcium phosphate. One way of reducing fouling is to heat the whey to 55–60°C for up to half an hour before the whey enters the ultrafiltration plant. Since the solubility of calcium phosphate decreases with increasing temperature, precipitation occurs before the actual ultrafiltration. In this way, precipitation on and within the membrane structure is avoided[15]. Similar pretreatment is recommended for milk.

Use of the permeate

Permeates from the ultrafiltration of milk and whey contain lactose, salts, low–molecular–weight nitrogen compounds etc. They have a high BOD (biological oxygen demand), but are not very useful directly. Further processing is necessary in order to obtain a more attractive product and thus a better economy; for example by hydrolysis to glucose/galactose syrup or fermentation to alcohol for the production of methane or for lactose production.

**Partial demineralization**

Membranes with selectivities in the intermediate RO/UF range have recently become available. Using this new class of modified thin–film composite membranes, which have a very high retention of low–molecular–weight organic substances and a fairly high salt permeation, it is possible to partially remove $Na^+$, $Cl^-$ and other monovalent ions from, for example, whey without a significant loss of lactose.

The process, sometimes referred to as nanofiltration, sometimes as loose reverse osmosis or ultra–osmosis, is a very interesting alternative to ion exchange and electrodialysis if moderate demineralization is required. An advantage of nanofiltration, compared with the other two processes, is that concentration and partial demineralization can be achieved simultaneously. Commercial plants for the demineralization of acid whey have been installed, for example, in Ireland.

Our own experiments with sweet whey have given the following results: The salt retention depends on the nature of the component as well as on the membrane itself. It is much lower for monovalent ions than for divalent ions. Increasing the NaCl content leads to a higher permeability of monovalent ions, and even negative NaCl retentions can be obtained[16]. Donnan exclusion is the preferred explanation.

**Concentration of milk and whey by RO**

RO is used for the concentration of milk and whey before transport or further concentration. It is also used to improve the quality of yoghurt made from the milk. The concentration for transport is usually 2–4 fold for whey, and 2–fold for milk. For yoghurt, skim milk is concentrated to 13–17%. At the end of 1988, the total membrane area for RO installed in the dairy industry was estimated at about 60,000 $m^2$, most of which was used for the concentration of whey[3].

## Microfiltration

Cross–flow microfiltration of milk to prolong its shelf life has been successfully developed by Alfa–Laval (Bactocatch process). Most of the milk components pass through the membrane while most of the micro–organisms are retained in the retentate. By using a correctly chosen membrane it is possible to retain more than 99.6% of the bacteria. The retentate is sterilized, mixed with the low–bacteria skim milk permeate and the mixture is then pasteurized.

By maintaing a constant transmembrane pressure (the pressure difference between the retentate and the permeate), capacities of 400–600 $l/m^2h$ can be obtained[17].

Similarly,whey can be microfiltrated with constant transmembrane pressure. Micro–organisms and part of the fat are retained. Such a plant is in operation in Sweden. Using a suitable form of pretreatment to avoid calcium phosphate precipitation, fluxes of 1250–1500 $l/m^2h$ have been obtained at 50°C for up to 16 hours. In these applications, ceramic membranes are used.

# FRUIT JUICES

## Clarification of juice

In juice processing, the process stream contains compounds such as pectins, cellulose, hemicellulose, starch and proteins, which cause an undesired turbidity when stored. It is thus necessary to clarify the juice. Traditional methods of fruit juice clarification are both time– and labour–consuming and involve the use of large fining tanks as well as large amounts of enzymes and diatomaceous earth.

Since the late 70's, ultrafiltration has been applied commercially for the clarification of fruit juice. Most ultrafiltration plants have been installed for apple juice clarification, but commercial systems are also in operation for grape, pear, pineapple, cranberry and citrous juices.

For juices with small amounts of suspended solids such as apple juice, yields of more than 97% are reported, while yields are limited to about 90% for high–suspended–solids feeds[9].

Enzymatic depectinization of the juice leads to a reduced viscosity and thus a higher flux. Pectinase is therefore added to the juice. However, in ultrafiltration clarification, the amount of pectinase added is only about one third of the amount used in the traditional process. Capacities at 50°C of 40—45 $l/m^2h$ for nondepectinized apple juice and 85–90 $l/m^2h$ for depectinized juice have been reported[18].

## Concentration of fruit juices

Fruit juices are concentrated in order to prolong their shelf–life and to minimize the costs of distribution and storage. Before retailing, the concentrated juice is diluted, pasteurized and packaged. Concentration normally takes place by means of vacuum evaporation in one or more stages. During this operation many of the volatile aroma compounds of the juice are lost in the vapour, resulting in reduced product quality. To maintain a high quality, aroma compounds must be recovered and added to the juice concentrate. For juices such as apple, pear and some berries, the vapour from the first of the evaporation stages is often taken to a distillation column where it is concentrated and cooled to a low temperature. The aroma concentrate is stored separately and then added to the diluted juice concentrate before pasteurization. On an industrial scale such distillation technique results in a very low yield. Besides, the aroma compounds are treated at a relatively high temperature for quite a long time, which has a negative effect on the quality of the final product.

Reverse osmosis is used commercially for the concentration of fruit juices. High aroma retention is reported using polyamide membranes[19,20]. However, due to the osmotic pressure, traditional RO is used only as a preconcentration stage to reach 20–25° Brix. For apple juice, fluxes have been reported to be about 35 $l/m^2h$ at 6.0 MPa and 50°C [21].

Separa Systems, a joint venture of the FMC Corporation and the Du Pont Company, has developed a "Freshnote" system with which juice can be concentrated to about 55° Brix. After clarification, the juice is processed in a series of hollow fine fiber reverse osmosis permeators at pressures between 10 and 14 MPa. The retentate is then recombined with the pasteurized bottom solids stream[22].

### Aroma recovery by pervaporation

Pervaporation, a membrane operation where minor liquid components of a solution can be removed and enriched, has been shown to be an interesting method for the recovery of aroma compounds from, for example, apple juice[19]. The possibility of using a low process temperature allows for very gentle treatment and thus an improved flavour compared with aroma recovered by distillation.

At Lund University we have obtained high enrichment factors, especially for esters and aldehydes, which are most important for apple flavour. Esters were, for instance, concentrated more than 100–fold during pervaporation using silicone rubber membranes, while the enrichment factors of the aldehydes ranged from 40 to 60[19]. In order to evaluate the process, more research is needed for these complex systems, e.g. coupling effects, costs etc.

## BEER

Low–alcohol beer is produced commercially using cellulose acetate membranes, through which ethanol as well as water and a substantial amount of the aroma compounds pass. To some extent the aroma losses may be compensated for in the brewing process. Low alcohol wine can be produced in a similar way.

In beer production, almost all the yeast and a significant proportion of the micro–organisms are removed in the traditional filtration step. Microbiological safety cannot, however, be guaranteed in this way. In order to prolong the keeping time, the beer is therefore normally pasteurized before tapping. Heat treatment of the beer can, however, lead to oxidation of aroma compounds, especially if the amount of dissolved oxygen is high. Pasteurization thus subjects the beer to a thermal load.

Removal of bacteria by cross–flow microfiltration is an interesting alternative to heat treatment. The thermal load is avoided, and the beer clarification is also improved, since particles passing through the traditional filter can be removed by microfiltration. One disadvantage in the use of microfiltration is the risk of loosing colour, bitter flavour compoments and foam stabilizing proteins. In short–term trials we found that by choosing a suitable pore size and an appropriate transmembrane pressure, it was possible to remove bacteria from the beer without retaining significant amounts of beer compounds. In order to optimize the process and to run a plant at a stable and high capacity for longer times, further studies must be performed and a suitable cleaning procedure must be developed[23].

## EFFLUENTS FROM THE POTATO STARCH INDUSTRY

Large volumes of waste water are obtained as a by–product in the processing of potatoes and wheat in the starch industry. Using potatoes as raw material, potato fruit juice is obtained as a by–product. The composition of a typical Swedish potato fruit juice is 2.4% crude protein, 1.1% ash, 0.5% starch, 0.4% glucose, 0.1% fat and fibres, giving a total solids content of about 5.5% and a BOD of approximately 16,000 mg/l. About 60% of the crude protein is regarded as being true protein. A little less than half of the total solids content in the potato fruit juice thus consists of proteins and low–molecular–weight nitrogen compounds, which are of potential value, both for human and animal consumption[24].

In most countries the potato fruit juice is irrigated. The potato proteins have, however, potential advantages, such as excellent functional properties and a high nutritive value. Work is now in progress in Sweden to recover potato proteins. Since the proteins are heat sensitive and denaturate if pasteurized, we are studying the possibility of removing micro–organisms by crossflow microfiltration without reducing the protein content. Control of the transmembrane pressure, as well as optimization of the protein solubility seems to be of great importance[25].

Before membrane processing, proper pretreatment is important to remove peel, fibres, starch etc. Other factors which must be considered are the foaming tendency of the potato fruit juice and the fact that potato fruit juice undergoes rapid degradation, which has a negative effect on the flux.

## TRENDS

Quality aspects and energy considerations as well as increased environmental awareness will certainly help to promote the use of membrane technology for liquid foods and food process effluents. The main limiting factor today is often the cost. Improved permeability, selectivity and flux as well as a reduced membrane cost will substantially further increase the use.

Membrane surface properties are of great importance. Membrane development will undoubtedly lead to improved performance and selectivity. Polymeric UF membranes with more hydrophilic properties are, for instance, being developed. However, the superiority of the new modified membranes still remains to be proven.

The use of inorganic microfiltration membranes is increasing. Composite inorganic membranes are under development. One example of such a membrane is a zirconia ceramic membrane with a nickel–based super–alloy mesh support.

The development of membranes with fairly high salt permeabilities and a very high sugar retention etc. will certainly be of advantage in the food industry, while the development of reverse osmosis membranes with increased resistance to oxidizing agents will facilitate the cleaning procedure.

Spiral modules have been used successfully for different food applications. There is a trend towards an increased use of this type of module for ultrafiltration applications because it is cheaper than plate and frame or tubular modules.

The development of RO modules with a high pressure limit allows higher degrees of concentration, as in the process for juice concentration described earlier.

Cross–flow microfiltration offers significant potential if fouling problems can be reduced. Much more research is needed to obtain a better understanding of the phenomena involved. The hydrodynamics and the start–up procedure are also of great importance, as shown in dairy applications.

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