Membrane filtration technology and its application in food industry

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ABSTRACT

Membrane processes are very important with advantages such as reduced energy consumption, mass transfer and high efficiency and ease of use. In membrane processes, different components are separated from each other due to the sieving mechanism, barrier transfer through the narrow pores of the membrane, and other interactions between the components and membrane materials (such as surface absorption and electric hobbing interaction). In a membrane separation system, a fluid with two or more components is placed in contact with a membrane that allows certain components of the fluid (water in the fluid) to pass through it more easily than other components. The physical and chemical nature of the membrane (pore size and pore size distribution) affects liquid separation. Filtration is the separation of materials based on their different physical and chemical qualities. By definition, filtration is an operation used to separate insoluble solids from liquids. Physical removal of microorganisms by filtration can be used to recover the solid discontinuous phase (cells) for production, e.g., concentrate starters, or to remove the continuous phase of microbial particles (air filtration, microbial filtration, surface filtration).

Keywords: Membrane technology, ultrafiltration,nanofiltration , reverse osmosis, food industry

1. INTRODUCTION

Membrane technology is an emerging technology and has become increasingly important in our life. A significant breakthrough for industrial applications of synthetic membranes started in the 1960s, although the earliest recorded study of membrane phenomena can be traced back to the middle of the eighteenth century (1). With nearly 50 years of rapid development, today, various membrane processes have found numerous industrial applications, which cover water and dairy purification, sea and brackish water desalination, wastewater reclamation, food and beverage production, gas and vapor separation, energy conversion and storage, air pollution control and hazardous industrial waste treatment, hemodialysis, proteins and microorganisms separation, etc. Membrane technology has greatly enhanced our capabilities to restructure production processes, protect the environment and public health, and provide new technologies for sustainable growth. The scope of the applications of membrane technology is still extending stimulated by the developments of novel or improved membrane materials and membranes with better chemical, thermal and mechanical properties or better permeability and selectivity characteristics, as well as by the decrease of capital and operation costs. This chapter provides a general review of membrane technology in terms of historical development, current status and future prospects. It can be seen that membrane science and technology have experienced a long period of development in laboratory studies. Although having enjoyed numerous industrial applications since 1960s, membrane technology still requires steady improvement to satisfy future broader applications.

1. Membranes, Membrane Classifications and Membrane Configurations

Membrane” has different meanings in different domains. In association with separation, concentration or purification processes, a membrane can be essentially defined as a barrier to separate two phases and be able to restrict the transport of various components in a selective manner conventional filter also meets the definition of a membrane; however, the term “filter” is usually limited to structures thatseparate particulate suspensions larger than 1–10 mm. There are many ways to classify synthetic membranes. They can be classified by the nature of the membrane material, the membrane morphology, geometry, preparation methods, separation regime and processes, etc. For instance, synthetic membranes can be organic (polymeric) or inorganic (ceramic/metal), solid or liquid, electrically charged or neutral in nature; they can be homogeneous or heterogeneous, symmetric or asymmetric in structure. Grouped by membrane geometric shapes, synthetic membranes can be flat, tubular or hollow fiber membranes. There are separation membranes to change the composition of mixtures, packaging membranes to prevent permeation, ion-exchange and biofunctional membranes to physically/chemically modify the permeating components, proton conducting membranes to conduct electric current, or non-selective membranes to control the permeation rate. Membranes have to be configured into membrane modules for practical applications Membrane modules are the core elements in membrane-based separation andpurification systems. In general, membrane modules are classified into three types: plate &frame, spiral wound and hollow fiber modules. Normally, the membrane surface to volume ratio is about 328–492 m^2/m^3 (100–150 ft^2/ft^3) for plate and frame modules, 656–820 m^2/m^3(200–250 ft^2/ft^3) for spiral wound modules and 6,562–13,123 (2,000–4,000 ft^2/ft^3) for hollowfiber modules. The key properties of efficient membrane modules are high packing density,good control of concentration polarization and membrane fouling, low operating and maintenance costs, and cost-efficient production[1].

2. Principles of membrane function

Membrane filtration refers to the separation of liquid compounds by means of membranes whose pore size is controlled, and the feed solution is passed through the membrane by a driving force.In membrane separation, the incoming flow passes parallel to the surface of the membrane and the way of penetrating into the membrane is a vertical flow. Therefore, filtration must be done in a closed system. Therefore, the membrane separation process is based on the selective penetration of one or more components from the liquid mixture into the membrane and passing through it. Membranes can be used in concentration or fractionation processes to produce two liquid streams with different characteristics. The remaining flow behind the membrane is called the residue or concentrated, and the part of the feed that passes through the membrane is called permeation[2].

3. The structure of the membranes

The membranes are in the form of a hollow fiber fiber or spiral structures made of cellulose acetate and synthetic materials such as polypropylene or polyfuron.

3.1 Thin interstitial fibrous membranes

They are in the form of a thin hair-like tubular structure, which is called a fiber. The fiber is twisted in a U shape. Thousands of these U-shaped fibers form bundles of fibers and are placed under pressure inside the tubular vessels, which causes an excessive increase in the smoothing surface, these pressurized vessels (tubes) cause to make the membranous fiber system very compact and efficient. The water has passed through the membrane and the condensed part (residual or excess) is left in the inlet part, and the other part of this water, which is filtered water and is also called seepage water, goes to the other side of the membrane. The water flow in the membrane can be from the inside to the outside or from the outside to the inside. If the flow direction is from the inside to the outside, it is called transverse flow, and if the flow direction is from the outside to the inside of the membrane, it is called cross flow. In the transverse flow type, the condensed part is on the inner side and the penetrating part is on the outer side of the membrane, while in the cross flow type, the reverse of this situation exists, that is, the condensed part is on the outer side and the penetrating part is on the inner side of the membrane.

3.2 Spiral membranes

They are in the form of a flat sheet that is wrapped around a central tube and collects the infiltrated water. This plate has an active membrane on the outside and a thick fibrous support or cover on the underside. Usually the two membranes are connected back to back with a separator between them. These units are twisted together and form the main membrane element. Membrane elements are placed inside a cylinder under pressure[3].

4. Classification of membrane filtration

4.1 reverse osmosis

This process was observed for the first time in 1748 by a French scientist named Jean-Antoine Nolte. This tube is the best tube known to pass water. In the reverse osmosis process, the densest possible membrane is used to separate liquids. Basically, in this type of membrane, water is the only substance that can penetrate it, and other substances such as bacteria, spores, fats, proteins, salts, sugars, minerals, etc. will not be able to pass through it. Was. The pore size of reverse osmosis filters is 0.0001 micron, as a result, water, which is a small molecule, is the only material that will pass through it. These waters are used for industrial purposes. Also, these filters are used for wastewater treatment and water reuse. This membrane can be used to remove phosphates, calcium, heavy metals and other substances[4]. Reverse osmosis schematic is shown in figure 1.

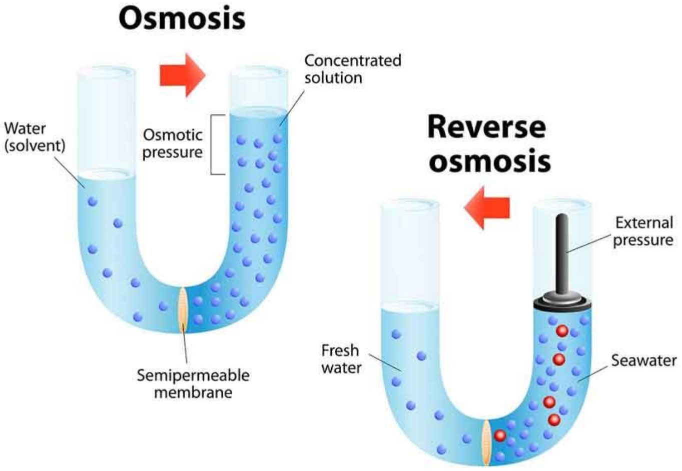

Fig.1. *Schematic of reverse osmosis*

4.2 Ultrafiltration

UF membranes were studied at the laboratory scale or small scale as early as 1907 (27), but they were firstly prepared with an initial goal of producing high-flux RO membranes. The first commercial UF membranes were introduced in the mid-1960s by Millipore and Amicon as a spin-off of the development of asymmetric RO membranes. UF membranes have their roots in commercial cellulose acetate RO membranes and thereafter were steadily developed in parallel with RO membranes. Different from RO membranes, no significant osmotic pressure is generated across the UF membranes because the porous structure (pore size 1–100 nm) allows the permeability of microsolutes (MWs < 300) through the membranes (29). UF membranes, practically, are used as a barrier to separate macromolecules, colloids and solutes with molecular weight larger than 10,000 from low molecular weight species. Although these species can produce anosmotic pressure, it is usually only a few bar. Thus, the hydrostatic pressure difference used as driving force in UF is in the range of 1–10 bars. The selectivity of UF membranes is basedon the difference in the size and surface charge of the components to be separated, the properties of the membrane as well as the hydrodynamic conditions. Most UF membranes have an asymmetric porous structure and are often prepared by the phase-inversion process. CA was the main membrane material in the first decade of UF. However, the chemical and thermal stabilities of CA are low and it has a relatively narrow range of pH tolerance and is highly biodegradable. Therefore, other polymers or polymer blends were employed to produce UF membranes, such as polyacrylonitrile, aromatic polyamides,polysulfone, polyethersulfone, polyvinylchloride and polyvinylidene fluoride. UF membranes prepared from these materials show a wide range of pH and temperature resistances, and are fairly resistant to chlorine, which significantly broaden their applications. The UF membrane configurations also varied from tubular to hollow fibers, spiral-wound and capillary modules by the end of 1980s. Thirty years after their emergence, UF membranes had successfully found a wide range of industrial applications (Table 1.4) which created a world wide market up to US$60 million for water treatment, US$44 million for food industry, US$130 million for medical devices and US$15 million for chemical industry. Two key industries were involved in the commercial development of UF. UF membranes were adopted for the recovery of electrophoretic paints from rinse water. Considerable saving of paints and water was achieved by using tubular CA membranes without requirement of thermal or chemical stability, and without UF the electrophoretic paint industry would have struggled. Another important application of UF membranes has been the dairy industry. Not only used for recovering proteins, lactose and lactic acid from whey, the membranes were also used to concentrate dietary milk or produce cheese. The double benefits in water pollution treatment and valuable products recovery made the dairy industry a large market area for UF membranes[5]. Ultrafiltration schematic is shown in figure 2.

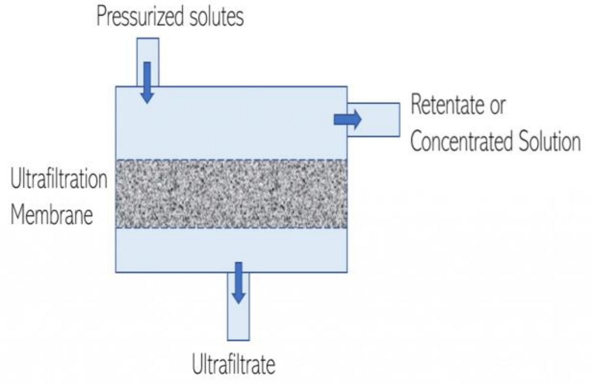

Fig.2. *Schematic of Ultrafiltration*

4.3 Nanofiltration

The term NF was introduced by FilmTec in the second half of the 1980s to describe a "RO process" that selectively and purposely allows some ionic solutes in a feed water to permeate through. It was derived from the membrane's selectivity towards noncharged solutes of approximately 1 nm cutoff . Within a few years, other membrane scientists began using the word and Eriksson (33) was one of the first who used it explicitly in 1988.As a matter of fact, such membranes with the selectivity between the RO and UF regions already existed in the 1960s and were categorized as open, loose, low-pressure RO, intermediate RO/UF, or tight UF membranes. Different from RO membranes which has nonporous structure and a transport mechanism of solution-diffusion, NF membranes operate at the interface of porous and nonporous membranes with both sieving and diffusion transport mechanisms. Bhattacharyya, Jitsuhara and Tsuru observed that charged UF membranes performed same features as NF in the case of salt retention. Therefore, it was acknowledged that NF performed an intermediate capability as "loose" RO (nonporous, diffusion) or "tight" UF (porous, sieving). This "loose" property of NF membranes enables them to be operated at higher water fluxes (water recoveries) with much lower pressure compared to RO membranes, that results in significant energy saving. In addition, most NF membranes are surface charged so that electric interactions also add to the transport and selective rejection behavior of NF membranes. NF membranes have a high permeability for monovalent salts (e.g., NaCl, KCl), but they are able to eliminate multivalent salts near completely and remove relatively small organic compounds. NF was used as an alternative to RO for the concentration and demineralization of whey in dairy industry. Till 1990, NF membranes had found their more applications in seawater softening, food, textile and mining industries . The NF-50 membrane was the first example of RO membrane capable of operation at UF membrane pressures. Characteristics of this membrane include 30–40% NaCl rejection, 85–90% $MgSO_4$ rejection, 98% sucrose rejection and 99% raffinose rejection. However, the first generation NF (loose RO) membranes made by CA possessed poor biological and chemical stability. They did not allow application in organic solvent due to the lack of chemical resistance of the membrane polymers against the solvents. The most important drawback of NF membranes is the problem to control the reproducibility of the membrane pore size and the pore size distribution. Moreover, NF membranes are liable to fouling, possibly resulting in important flux decline[6]. The schematic of nanofiltration is shown in Figure 3.

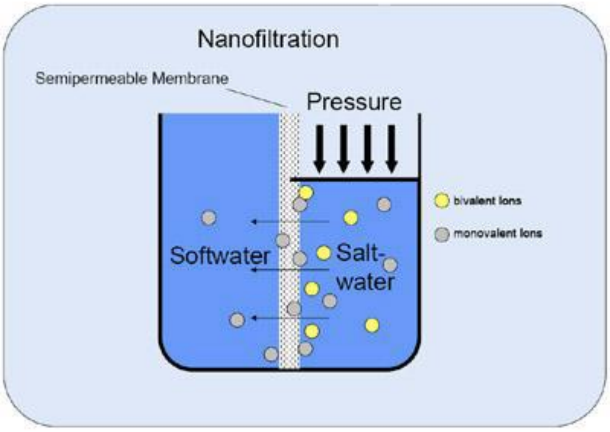

Fig.3. *Schematic of Nanofiltration Membranes*

4.4 Microfiltration

MF membranes are used for separation of impurities (particles, viruses, and bacteria) with a size range of 0.1–10 mm from a solvent or other low molecular weight components. The separation mechanism is based on a sieving effect and particles are separated according to their dimensions although some charge or adsorptive separation is possible. The applied pressure in MF is quite low (<2 bars) compared with other filtration processes (43). Systemic studies on MF membranes started at the beginning of the twentieth century by Bechold, who made membranes from different compositions of the casting solution and 14 A.G. (Tony) Fane et al. found that pore size could be changed. He also applied bubble point measurement to determine the maximum pore size of membrane filters and this technique is still used today. Around 1918, Zsigmondy and Bachmann developed the first method to produce nitro-cellulose membranes that were applicable on a commercial scale. The term “membrane filter” was used by them for the first time. The membrane filter technique became important just after World War II as it was applied to the bacteriological examination of water supply systems, which had inspired extensive studies on the membrane filtration technology. In 1950, Goetz developed a new method capable of producing membranes with improved performance and Millipore Co. was then setup based on it in 1954. The first commercialized application of MF membranes was in biological and pharmaceutical manufacturing in the 1960s. In the following 20 years, MF membranes were mainly used in sterile filtration (microorganisms removal) in the pharmaceutical industry, and final filtration (particle removal) of the rinse water in the semiconductor industry. Not so stringent as in the pharmaceutical industry, MF was also used in sterilization of beer and wine, as well as clarification of cider and other juices, easily and economically. It was not until the mid- 1980s, that MF was introduced to water treatment industry because of its cost effective benefit. The application of MF (and UF) in water treatment gained in momentum following the cryptosporidium outbreak in the USA in 1992. Stricter regulation on pathogen removal for water supply have seen a major shift to the low pressure membrane processes. Before 1963, membrane microfilters were predominantly made of nitro-cellulose or cellulose esters. The development of highly resistant membranes such as polypropylene, polyamide and polysulfone enables the MF technique to be used as a large-scale separation tool[7]. The schematic of microfiltration is shown in Figure 4.

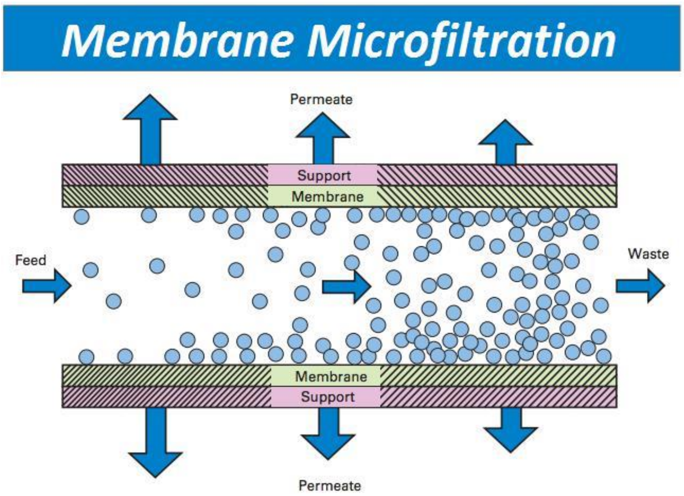

Fig. 4. *Schematic of Microfiltration*

5. Advantages of the membrane process

- Reducing energy consumption due to no phase change
- Not needing a lot of space and having a small volume
- Variation in shape and size
- Low pressure drop and high mass transfer
- For dilute solutions, high separation efficiency
- Low need for solvents and additives
- Simplicity of membrane design
- Eco-friendly
- Their application in industrial scales

5.1 Disadvantages of membrane processes

- Concentration polarization
- Clogged membranes
- Short life span of the membrane
- High cost of construction[8].

6. Application of membrane filtration in food industry

6.1. Milk and dairy industry

Most of the industrial developments of membrane technologies in the food industry originate from the dairy industry. They have been more or less tightly linked to the progress in membrane operations: asymmetric organic membranes by the late sixties; composite inorganic membranes in the early eighties; porous ceramic membranes with multi-channel configuration in the early nineties which has enabled industrial application of the concept of uniform transmembrane pressure. UF is the most widely used process in the world dairy industry. The membrane area of RO has stabilized around 60,000 m^2, mainly for whey concentration. MF is developing due to its capability to retain, partly or totally, particles (micro-organisms, casein micelles, fat globules), and NF is given a large field of applications due to its intermediate selectivity (200– 1000 Da) between UF and RO (demineralization, de-ionization, purification) in particular for whey protein valorization. The integration of membranes has been implemented throughout the milk and dairy processing chains milk reception, cheese making, whey protein concentration, fractionation of protein hydrolysates, waste stream purification and effluents recycling and treatment all are membranes[9].

6.2 MF for Globular Milk Fat Fractionation

The separation of milk fat globule to two fractions (small globules < 2 mm versus large globules > 2 mm) has been realized by a patented process using special microfiltration membranes103–104. Large ranges of operating conditionshave been tested: 1.8–10 mm pore size, 0.2–1.75 bar transmembrane pressure, 37–55º C temperature, 4–8 ms^{-1}tangential flow velocity and 2–20 volume reduction ratio. The raw material may be: whole milk, fat enriched milk, or cream. Transformation to drinking milks, yoghurts, sour cream, camembert, Swiss cheese and butters were also realized. It is claimed that, except butter, the use of the small globule fraction yields more unctuous products and finer textural characteristics compared to products made from untreated or large globule cream[10].

6.3 whey

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 Vm^{2}h 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[11].

6.4 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 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[12].

6.5 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. [13]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-suspendedsolids feeds9• 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^{2}h for nondepectinized apple juice and 85-90 l/m^{2}h for depectinized juice have been reported 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. 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^{2}h at 6.0 MPa and 50°C 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[14].

6.6. 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[15].

6.7 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. 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. In order to evaluate the process, more research is needed for these complex systems, e.g. coupling effects, costs etc[16].

6.8 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[17].

6.9 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 obtained16. Donnan exclusion is the preferred explanation[18].

6.10 Purification of municipal wastewater and water needed in industry

❖ Microfiltration

Microfiltration membrane is the most widely used and cheapest method of membrane filtration in wastewater treatment. Currently, the use of this membrane filtration process in biological treatment and in MBR processes is of great importance. Microfiltration is used to reduce turbidity, remove remaining suspended substances and reduce microorganisms before the disinfection unit and in the pretreatment stage of the reverse osmosis membrane.

❖ Ultrafiltration

Ultrafiltration membrane applications are very similar to microfiltration. Of course, this membrane filtration process in wastewater treatment is able to remove some compounds with high molecular weight such as colloids, proteins and carbohydrates, but it is not able to remove sugar and salt. The biggest difference between UF and MF is the ability of the ultrafiltration membrane to remove viruses. The main application of the ultrafiltration membrane filtration process in the industry is the production of high purity washing process water[19].

❖ Nanofiltration

Nanofiltration, also known as low pressure RO, is capable of removing particles as small as 0.001 microns. This membrane is used to remove soluble substances such as polyvalent ions of hardness. The advantage of this membrane filtration method is the removal of lime hardness, the production of water that meets the strict requirements of water quality for use in wastewater treatment. Due to the removal of organic and mineral substances, bacteria and viruses, the amount of disinfectant used is minimized.

❖ Reverse osmosis

Reverse osmosis membrane filtration method is widely used in desalination. In wastewater treatment, RO is used to remove dissolved substances in the advanced treatment effluent after deep filtration and microfiltration. The reverse osmosis method is capable of removing ions, but it requires high pressure to deionize water[20].

6.11 Conclusion and 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[21].

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