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MEMBRANE SEPARATION TECHNIQUES IN WINE AND BEER PRODUCTION

During beer and wine production processes there are several solid–liquid separation steps which are currently carried out using earth filtration, plate filtration or centrifugation. Even though the current separation and finishing techniques are well known and optimized, they have some drawbacks (e.g. they generate a large amount of solid residue). Membrane techniques make it possible for beer and wine industries to carry out the solid–liquid separation steps without generating solid residues, and to obtain microbiologically stable products or concentrates, without the need for thermal treatment. Despite the numerous advantages that membrane techniques offer to the wine and beer industries, there is one main drawback: membrane fouling, which reduces permeate fluxes and modifies the membrane separation properties. Most of the research in the field of membrane filtration is addressed to prevent and/or reduce membrane fouling using several methods (backflushing, backshocking, pulsing flux), and to characterize and identify the compounds responsible for membrane fouling.

Of the potential applications of crossflow microfiltration in brewing, two are particularly interesting: the filtration of beer after aging and the recovery of beer from tank bottoms. At present crossflow microfiltration is still a non-competitive technique in comparison to earth filtration for beer filtration after aging, since none of the existing membranes on the market can satisfy all the requirements of the process. On the other hand, almost all the membranes installed in breweries all over the world are used to recover beer from tank bottoms. According to crossflow microfiltration studies it is possible to recover between 1 and 2% of the total beer production from the tank bottoms. In the wine industry, crossflow microfiltration can cobine clarification and microbiological stabilization in a single continuous operation. However, low flow rates and higher compound retention are the main problems. Membrane techniques have some other uses in the wine and beer industries, such as electrodialysis for tartaric stabilization in the wine industry, reverse osmosis for must concentration and dealcoholisation, and pervaporation for wine and beer dealcoholisation.

1. INTRODUCTION

In beverage production processes there are several solid–liquid separation steps: the separation of solid particles before fermentation, clarification and stabilization processes after fermentation, and the final polish or microbiological stabilization of the product. These separation processes, which take place during beer and wine production, are currently carried out using earth filtration, plate filtration or centrifuga-

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tion. Even though the current separation and finishing techniques are well known and optimized, they have some drawbacks (e.g. they generate a large amount of solid residue). On the other hand, pasteurization and concentration processes are currently carried out using thermal processes, which lead to a significant loss in aroma compounds, and which are expensive in terms of energy. Membrane techniques make it possible for beer and wine industries to carry out the solid–liquid separation steps without generating solid residues, and to obtain microbiologically stable products or concentrates, without the need for thermal treatments. Table 1 shows a summary of membrane applications in the beverage industry, and Table 2 lists the potential applications and advantages of crossflow microfiltration (CFM) during beer production. Finally, other membrane techniques, such as reverse osmosis or pervaporation, allow new products to be obtained and current processes to be improved.

Despite the numerous advantages the membrane techniques have for the wine and beer industries (gentle treatment of the product, little generation of solid residues, greater efficiency), there is one main drawback: membrane fouling, that is to say, the deposition and/or adsorption of material on the membrane surface and/or its pores. Fouling changes the performance of the membrane because it reduces the flux and modifies its separation properties. Methods of reducing fouling, particularly in crossflow microfiltration, will be discussed below. Another disadvantage of membrane techniques when applied to concentration is that the maximum degree of concentration is restricted by viscosity and osmotic pressure if reverse osmosis is used.

Table 1

Summary of membrane applications in the beverage industry (Mohr et al., 1989)

Membrane application	State of development	Potential savings (trillion Btu)
	Beer applications	
Microbe removal from draft beer	Commercial	1
Alcohol removal	Commercial for wine in Europe, little market in USA. Membrane separations appear viable	
Beer recovery from tank bottoms and spent yeast slurry	Commercial with short payback, but is competing with standard filtration	<<1
	Wine applications	
Juice/must concentration	Commercial use should develop as membranes for RO fruit juice concentration are developed for other uses	<1
Clarification	Commercial	
Tartrate removal	Very little use	<<1
	Generic applications	
RO of wash water for reuse	Tested in fruit/vegetable processing, not viable economically	1

Table 2

Potential applications of crossflow microfiltration in brewing (Burrel et al., 1994)

Application	Current technology	Advantages of using crossflow microfiltration
Beer clarification	Earth filtration (diatomaceous earth)	Prevents the generation of dust during earth manipulation. Prevents the generation of solid residues
Beer recovery from tank bottoms	Centrifugation or press filter	Higher product quality
Sterilization	Flash-pasteurization or multistage cartridge filters	No heat effects on the product. Lower cost due to cartridge replacement

2. SEPARATION STEPS DURING BEER PRODUCTION

To better identify the separation steps that take place during beer production, a typical brewing process is illustrated in Figure 1, and the separation processes are summarized in Table 3. Barley malt is prepared by wetting grain, allowing it to germinate, and then drying it. The malt is ground into a grist and mixed with warm water to form a mash. A portion of the barley mash is mixed with ground unmalted cereal grains, such as rice or corn. This mixture is boiled in a cereal cooker for about half an hour to rupture the insoluble starch cells and convert the starch into a soluble from. The adjunct mash and barley malt mash are mixed with water and allowed to stand. After approximately 30 minutes, hydrolysis converts 75 to 80% of the soluble starches into maltose and glucose.

The completed mash is strained to remove the spent grain, malt, and husk fragments. The extract from the mash is a sweet, watery liquid, called wort. In the brewing kettle, the wort is brought to the boil and hops are added. The wort is boiled for 1 to 2 hours, and the characteristic bitter flavor components are extracted from the hops, the residual enzymes are destroyed, and undesirable proteins are coagulated. Because the resulting mixture has been boiled, it is sterile and ready for subsequent fermentation.

Coagulated protein is separated by gravity and the wort is decanted. In preparation for fermentation, the wort is cooled to 10 °C. Yeast is added and the wort is briefly oxygenated to assist the fermentation process. Fermentation requires about a week. Actual fermentation time depends upon the specific properties of the desired product. Refrigeration is required during the fermentation process to remove the heat which results from the conversion of fermentable sugars into ethanol and carbon dioxide. Nearly all of the sugars are fermented.

In the production of lager beer, yeast settles on the bottom of the tank and the beer is decanted. The remaining liquid, referred to as the tank bottoms, contains most of the yeast and from 2 to 4% of the total beer production. The fermentation tank bottoms typically contain 1 to 15% solids, primarily yeast cells. The yeast is recovered for reuse in fermentation. Lager beer requires 2 to 6 weeks of aging at nearly 0 °C. Decanting and filtering are performed during the aging process to remove the additional yeast, which settles on the bottom. Immediately before packaging, the beer is filtered so that clarity is high. Draft beer requires no special treatment to preserve it and it is ready to be kegged. Canned or bottled beer must be pasteurized or cold membrane filtered before packaging.

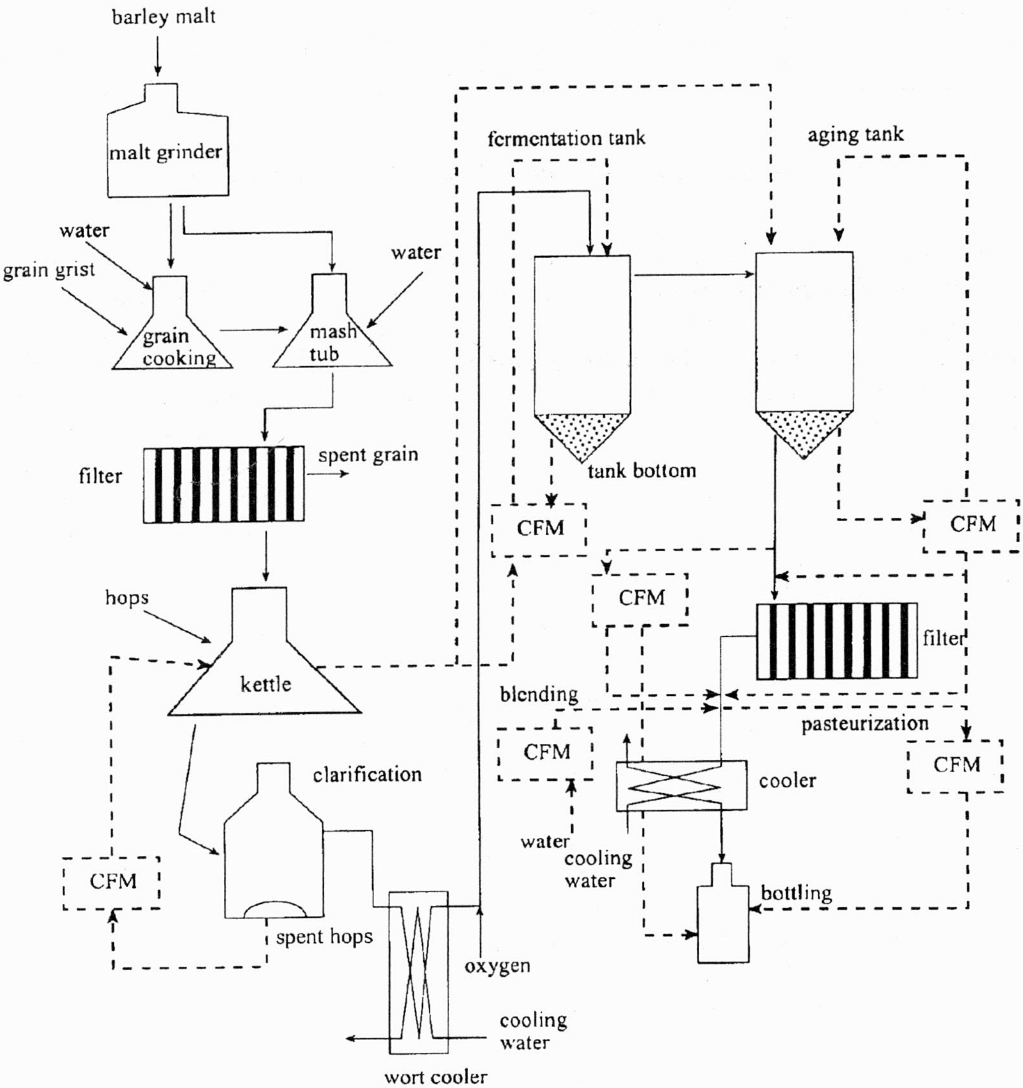

Fig. 1. Flow diagram for beer production (Blanpain and René, 1998)

Table 3

Summary of separation steps during brewing (Blanpain and René, 1998)

After the operation	Type of operation	Materials separated
Mashing	Filtration	Must/grain
Boiling	Sieving	Must/husks
Fermentation	Filtration	Beer/yeast
Aging	Clarification	Beer/yeast + colloids

3. CROSSFLOW MICROFILTRATION IN BREWING

As mentioned above, most of the current separation processes carried out in breweries use diatomaceous-earth filtration. Taking into account that approximately 140 g of diatomaceous earth (DE) are needed per hl of filtered beer, a total of 350,000 Tm of DE are used annually in beer production. In the light of these data, crossflow filtration, and in particular microfiltration, appears to be a promising alternative separation technique. The advantages of crossflow microfiltration over DE filtration are the following:

- No need of diatomaceous earth utilization.
- The process is improved because clarification and sterilization are possible in a single continuous operation.
- The performance improves because the process is automatic.
- The equipment can be cleaned in-place.
- There are a considerable number of membrane modules on the market which are suitable for these processes.

Of the potential applications of crossflow microfiltration in brewing (Figure 1, discontinuous line), two are particularly interesting: the filtration of beer after aging and the recovery of beer from tank bottoms.

FILTRATION OF BEER AFTER AGING

In this stage, crossflow microfiltration could replace earth filtration and pasteurization by a single continuous operation. Theoretically it is possible to obtain a clear and sterile beer after microfiltration, but most of the experimental studies carried out do not provide solutions to all the different problems. The two main points of interest that are being studied are the fouling mechanisms responsible for the decrease in permeate, and the possibility of cleaning and regenerating the membranes in order to increase the life cycle of the modules.

At present crossflow microfiltration is still a non-competitive technique in comparison to earth filtration, since none of the existing membranes on the market can satisfy all the requirements of the process (Blanpain and René, 1998). Therefore, diatomaceous earth filtration is still the standard procedure in the filtration of beer after aging. Finally, it should be noted that membrane filtration is widely used to carry out the final beer sterilization. However, dead-end microfiltration using membranes of a nominal pore size between 0.2 and 1 μm is the most commonly used.

RECOVERY OF BEER FROM TANK BOTTOMS

After fermentation, most of the yeast is collected as surplus yeast. After beer aging has been completed and the yeast, along with other insoluble material, has settled, the so-called tank bottoms are collected as by-product. Typically, the total amount of surplus yeast solids produced in a lager fermentation is about 0.27–0.36 kg/120 l of final product. The solids in surplus yeast include pure yeast solids, beer solids, and trub solids. Trub solids contain approximately the same amount of protein as yeast solids (40–50%) and their removal is not required if yeast is to be sold as animal feed. When yeast is sold for food uses, removal of both trub solids and beer solids is generally necessary.

At the end of fermentation, yeast is collected from the fermenters by one of the following methods:

- Pulling (raking) settled yeast from the bottom of the fermenter.
- Separating yeast from the entire fermenter contents using centrifuges.
- Pulling settled yeast, followed by clarification of the rest of the fermenter contents in centrifuges.
- Using various skimming systems when top-fermenting yeasts are employed.

Surplus yeast pulled from the bottom of the fermenters or aging tanks usually has 10–14% total solids. This surplus yeast may contain as much as 1.5–2.5% of the total beer production. It is usually worthwhile to recover at least a portion of this beer, particularly in countries where excise taxes are paid on all the beer produced in fermentation, including that which is wasted.

Methods or recovering entrained beer from surplus yeast have been reviewed in detail for 90 breweries in Great Britain (Huige, 1995). The findings are as follows:

Rotary vacuum filter. A continuous filter which requires little operator attention and has fair to good filtrate clarity. Some of its drawbacks are that: (a) it requires a filter aid, (b) the concentration of dissolved oxygen in recovered beer is high, and (c) the filter cake solids are low (22–25%).

Plate and frame press. Cake dryness is low (limited maximum inlet pressure). Filtrate quality is fair to good, but it is labour-intensive.

Recessed plate press. Recovers up to 90% of the entrained beer and yields cake solids of 26–30%. Dissolved oxygen levels are low. A filter aid is only required for tank bottoms. Requires operator attention during cake discharge and must operate full.

Pressure leaf filter. For example, an open mud discharge filter. Generally more automated, more flexible, but more expensive. Cake moistures from 26–30%. Filtrate quality is good after initial recycle.

Decanter centrifuges. Can be used to further concentrate yeast slurries from centrifuges or aging tank bottoms to about 25% solids. Filtrate clarity poor, but low labour requirements.

Membrane filter press. After it has been filled, the cake can be compressed by expanding a diaphragm. It makes it possible to process yeast slurries of different volumes and concentrations. High capacity (cycle time of 1.5 h vs. 2–3 h with others). Cake solids high (30–35%), filtrate quality excellent. Operator attention required during cake discharge only.

Almost all the membranes installed in breweries all over the world are used to recover beer from tank bottoms. Crossflow microfiltration is used to concentrate tank bottoms from 12–15% of solids to 20–22%. The beer recovered by this procedure is driven to the production main stream and mixed with beer before or after the clarification in a proportion that may range from 2 to 5%. According to *crossflow microfiltration* studies it is possible to recover between 1 and 2% of the total beer production from the tank bottoms, yielding a cake solid of 23% (dry weight). A typical crossflow microfiltration unit consists of ceramic tubular membranes (0.4–0.8 μm), with a diameter of 4–6 mm, designed to process the high viscosity yeast suspensions.

4. CROSSFLOW MICROFILTRATION IN WINE MAKING

A typical wine production process is shown in Figure 2. The grapes are separated from the stems and crushed. Depending on the variety of wine being produced, the skins may or may not be separated from the crushed grapes. The juice is extracted from the crushed grapes using dynamic draining or pressing. The juice, called must, is preserved by the addition of sulfur dioxide. The must is clarified by centrifugation, settling or filtration, after which it is pumped to the fermentation tanks. Yeast is added to fermentation tanks and fermentation begins. Sulfur dioxide prevents oxidation during the clarification process and helps to stabilize the wine biologically. Repeated decantation and/or filtration using fining agents clarifies the wine. The concentration of tartrates is reduced by either prolonged chilling or ion-exchange (this latter procedure in USA and Australia). A final filtration before aging enhances clarity and ensures that all the yeast has been removed. Aging assists the clarification of the wine and, more importantly, allows the flavor components to mature. The wine is then blended to meet product requirements. Sterile filtration or pasteurization is performed immediately before packaging.

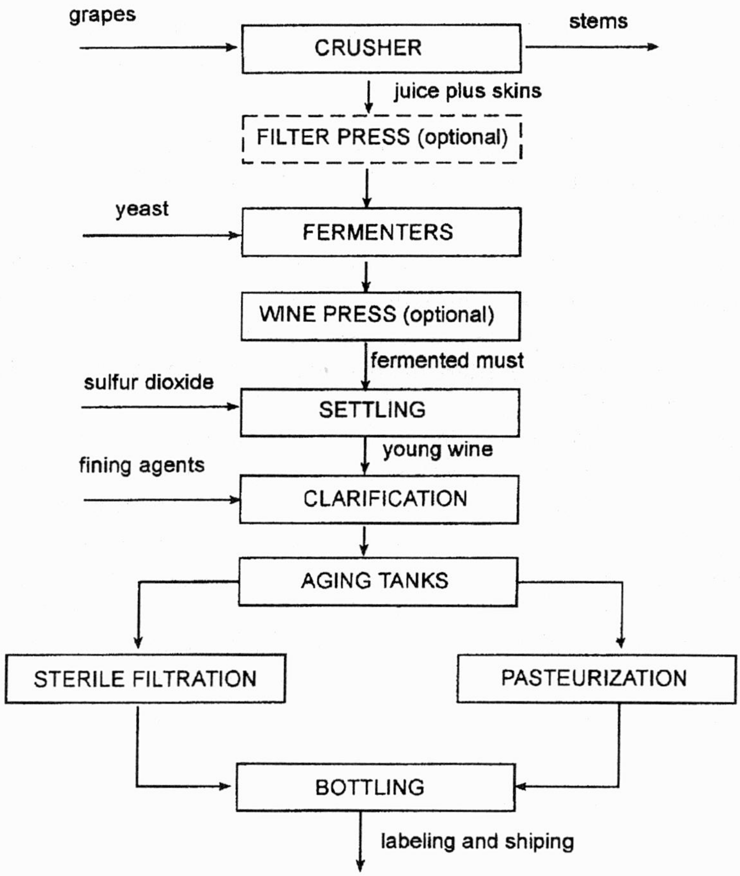

Fig. 2. Typical wine production process

As mentioned above, after fermentation wine is cloudy due to the presence of microorganisms, cells or cell debris, fining agents introduced during fermentation and aggregates. Therefore, before bottling, a number of operations have to be performed to clarify and stabilize the wine. Traditionally, wine is clarified using settling or dead-end filters with DE or cellulose plates. A final membrane filtration (dead-end mode) using 0.65 or 0.45 μm membranes is carried out before bottling to ensure microbiological stability.

Crossflow microfiltration combines clarification and microbiological stabilization in a single continuous operation, and has all the advantages mentioned above for the beer industry, basically from an environmental point of view, since it reduces the energy consumption and the solid waste disposal. The main drawbacks of crossflow microfiltration in the wine industry are the low flow rates, which means that it cannot compete economically with current clarification techniques, and the retention of certain compounds, which can lead to defects in the final products.

Both problems, low flow rates and higher compound retention, are the direct result of membrane fouling. Therefore, before crossflow microfiltration and other membrane techniques can be widely used in the wine industry, there is a need for further research into the systems to minimize membrane fouling during filtration, and also to determine which wine compounds are most responsible for it.

CROSSFLOW MICROFILTRATION IN WINE PRODUCTION

The first trials using membrane techniques in wine processing were carried out with ultrafiltration membranes, which lead to removal of important wine constituents

Table 4

Experimental results of crossflow microfiltration for wine (Escudier et al. 1998)

Membrane	Pore diameter (μm)	Type of wine	Flux (l/h m^2)	PR* (%)	References
Alumina, tubular	 0.2	 red (1)*	30 76	46 54	Feuillat et al., 1987 Belleville et al., 1992a
Alumina ZrO_2, tubular	0.2 0.2 0.2	red (2)* white (2)* red	14–85 128–250 80–115	22–27 27–40 31–67	Serrano et al., 1992 Feuillat et al., 1987
Carbone ZrO_2, tubular	0.06 0.14	red	83 100	38 16	Feuillat et al., 1987
PVDF, flat	0.4 0.4 0.1and 0.2 0.4 and 0.8	red (2)* white (2)* red (1)* red (1)*.	10 70 16–17 33	39 50 n/a n/a	Serrano et al., 1992 Jaffrin et al., 1993
Polypropylene, tubular	0.2 0.2 0.2 0.2	white (2)* red (1)* white (1)* white (3)*	34 100 100–150 200	n/a n/a n/a n/a	Berger, 1988 Gaillard, 1989
Polysulfone, tubular	0.05	red (1)*	50–85	n/a	Veen et al., 1987
Polyethersulfone, tubular	0.2 0.2 0.2	white (1)* red (1)* rosé (1)*	60–130 30–110 90–200	18–27 24–35 15–17	Cameira dos Santos, 1995

*PR – polysaccharide retention; (1) unclarified; (2) with fining agents; (3) clarified.

(López et al., 1992). So subsequent studies focussed on crossflow microfiltration. Table 4 summarizes some experimental studies on crossflow microfiltration in wine clarification. As can be seen, the flow rates obtained by different authors vary considerably and this is highly correlated with the variability of the experimental conditions (transmembrane pressure, membrane type, crossflow velocity), and of the wine (grape variety and pre- and post-fermentation practices). As can be seen in Table 4, the average flow rate is between 30 and 100 l/(h m^2). However, such factors as crossflow velocity and temperature will increase the flow rate.

When CFM was used, the clarification and microbiological results were positive as long as the pore diameter for microorganism retention was appropriate. This is one of the points on which CFM performs better than traditional clarification methods. On the other hand, the high retention of certain wine compounds is considered deleterious (Escudier et al. 1998). The most common criterion in enology for evaluating membrane selectivity is the total colloid retention (TCR), which essentially measures the content of polysaccharides, since these are the compounds which are most affected by microfiltration.

5. PREVENTION OF MEMBRANE FOULING DURING BEER AND WINE FILTRATION

Membrane fouling is clearly one of the main drawbacks to a more widespread use of crossflow microfiltration during beer or wine production. In order to improve CFM performance there are certain techniques that have been, or are currently being tested:

Backflushing. During the filtration mode the direction of the permeate flow through the membrane is periodically reversed, so that the backflushed permeate can remove the formed cake layer. As no filtration occurs during the backflush process and some permeate is lost, the backflushing process needs to be optimized. Typical operation conditions are a backflush every 5–15 minutes for 10–60 seconds. Although permeate is very often used for backflushing, in some cases a gas can also be used. Lüdemann (1987) used a compact plant with a polypropylene membrane with a filter area of 10 m^2 (Figure 3) to carry out white and red wine filtrations. He concluded that improving the backflushing efficiency made it possible to stabilize the filtration output at a higher level than the dead end filtration mode.

Backshocking. Backshocking is a variation of backflushing which uses high frequency and extremely short duration times. Wenten et al. (1994) applied this technique using reversed asymmetric hydrophilic polyethersulfone membranes (0.6 μm average pore size) to beer clarification. The combination of reversed membranes (the more open side towards the feed) and backshocking (60 ms every 1–5 s) allowed filtration at low crossflow velocities with very stable permeate fluxes. They also found very good transmission of high molecular weight components and very low turbidity in the permeate. The application of this technique to wine filtration is still not feasible, since some experiments with red wine using a polyether sulfone membrane (0.5 μm) resulted in a low polysaccharide retention, but no substantial increase in permeate fluxes (Escudier et al. 1998).

Pulsing flux. This differs from backshocking in the duration of the reverse filtration, which can be as low as 0.03 to 0.005 Hz (Escudier et al., 1998). When this technique has been used with organic membranes permeate fluxes have increased between 15 and 46%. For mineral membranes permeate fluxes are reported to decrease approximately by 10%, but polysaccharide retention was about 40% lower than normal CFM.

Besides the studies which attempt to reduce membrane fouling during crossflow microfiltration, considerable effort has been made to identify and characterize the compounds responsible for membrane fouling during wine and beer filtration. Even though macromolecules present in beer and wine (proteins, polyphenols, polysaccharides, etc.) are much smaller than the pore size of typical microfiltration membranes, they cause significant fouling. However, detailed studies of fouling mechanisms caused by polysaccharides and polyphenols are relatively scarce. Bellevile et al. (1990) studied the fouling of an inorganic tubular alumina membrane during red wine microfiltration and attributed it mainly to polysaccharides and polyphenols. Recent work by Vernhet et al. (1997) has covered polysaccharide and tannine adsorption on polymeric membranes (polyvinylpyrrolidone modified with polyethersulfone and polyvinylchloride) in static conditions. Their results indicate that the adsorption of polysaccharides and tannins is dependent on membrane polarity. Polyphenol adsorption is stronger on the more polar membrane, while the polarity of the membrane surface limits polysaccharide adsorption. However, it is well known that these results cannot be extrapolated to dynamic conditions during membrane filtration. Gan et al. (1997) studied membrane fouling during the filtration of beer with inorganic membrane and concluded that the flux decreased mainly because of internal fouling caused by carbohydrates. Although there is no related work on fouling mechanisms during microfiltration of fermented beverages using polymeric membranes, some pilot-plant scale work has been reported by Lüdemann (1987), suggesting that this type of membrane may be promising for industrial applications.

Czekaj et al. (1998) characterized membrane fouling of beer and white wine using 0.2 μm cellulose acetate and polycarbonate membranes under dynamic conditions. The results indicate that the initial macromolecular contents and turbidity of the wine and beer samples have a marked influence on the kind of fouling during microfiltration. Membrane fouling during beer microfiltration was highly correlated with the initial macromolecular contents and also with the surface porosity of the membrane. When a cellulose acetate membrane (highest surface porosity) was used, the beer sample with the highest initial macromolecular content caused greater fouling, while when a polycarbonate membrane (lowest surface porosity) was used, membrane fouling was independent of the initial macromolecular content. In the experiments with white wine, the initial turbidity of the samples as well as the membrane mor-

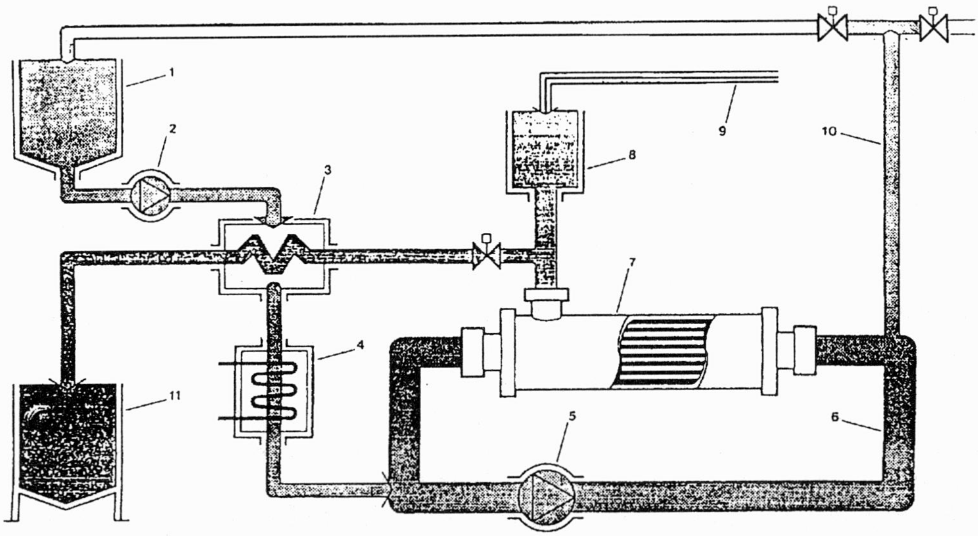

Fig. 3. Schematic representation of a crossflow microfiltration unit with backflushing (after Lüdemann): 1 – feed tank, 2 – feed pump, 3 – heat exchanger, 4 – heat exchanger with heating circuit, 5 – circulating pump, 6 – tangential flow circuit, 7 – ENKA Microdyn@ crossflow module, 8 – diaphragm plunger for backflushing, 9 – pressurized air, 10 – retentate outlet, 11 – filtrate tank

phology controlled membrane fouling. Finally, the study concluded that a previous sample ultrafiltration (100 kDa) almost completely eliminated the particles responsible for external fouling.

6. OTHER USES OF MEMBRANE SEPARATION TECHNIQUES IN THE WINE AND BEER INDUSTRIES

TARTARIC STABILIZATION

Calcium and potassium tartrates are very poor solubility salts found in wine. To prevent these salts from precipitating after wine is bottled and shipped, a stabilization process (referred to as cold stabilization or tartaric stabilization) is performed after fermentation. The traditional method consists in adding potassium tartrate crystals, which serve as nucleation sites for the crystallization, and decreasing the temperature to approximately –3 °C. Of the new tartaric stabilization techniques, ion exchange and electrodialysis are the most promising. Cationic exchange resins are used in Australia and USA to stabilize table wines. The main disadvantage of the process is the number of ions introduced into the wine by the exchange. On the other hand, electrodialysis has proved to be a suitable process for stabilizing wine against tartrate precipitates.

CONCENTRATION

Must concentration by reverse osmosis

Food processing applications such as dewatering and concentration of foodstuffs were among the first uses of reverse osmosis technology. Food processing applications were a logical use of reverse osmosis because, where practical, the technology offers many potential advantages over conventional technologies used by the food processing industry. These advantages include: (1) low relative energy requirements and low costs; (2) lower processing temperatures and reduction of thermal damage to food during processing; and (3) simpler system designs. However, for reverse osmosis membranes to be effective, they must be capable of operating on feed streams of high osmotic pressures and high concentrations of suspended solids. For this reason, hybrid systems are often used: reverse osmosis is used to partially dewater and concentrate the product, and a conventional process (such as evaporation) is used to complete the concentration process. Sugar retention by reverse osmosis membranes is good (>99.5%) (Escudier et al. 1998), and the sensorial quality of must treated with reverse osmosis is excellent. Reverse osmosis can also be used to remove water, thus concentrating wine destined for distillation.

DEALCOHOLISATION

Reverse Osmosis

This technique can be used to obtain an almost alcohol-free beverage (wine or beer). In the process, the fermented beverage flows over a semipermeable membrane under high pressure. The membrane is permeable to water, alcohol and other small molecules. The permeability of the membrane governs the extent to which alcohol and aroma compounds are removed. Mohr et al. (1989) used a pilot-scale system to demonstrate that ethanol can be selectively removed from beer with no loss of extract or flavour components. A reverse osmosis spiral-wound membrane was used to reduce the ethanol content by 74%. Water with the ethanol permeated the membrane but very few extract, protein or flavour components were removed. The resulting beverage is concentrated, and can then be adjusted to the desired alcohol concentration using different process flow schemes:

- Batch concentration: makeup water is added either before or after the beer is processed. This method is unsuccessful because components in beer are adversely affected when their concentrations are altered, and membrane foulants affect membrane performance and alter the taste.
- Semi-batch operation: makeup water is added to the beer as the ethanol and water are removed from the permeate. This means that concentrations of the components rejected by the membrane are approximately constant.
- Feed and blend operation: low-alcohol beer is continuously removed from the system while makeup water is continuously added.

Some membranes have been developed for the dealcoholisation of wine. Their ethanol permeability is low and this means that they have a variety of applications, such as adjusting the alcohol content of wines to market demand or reducing energy costs during the distillation of fermented alcohol. It has been reported that from a wine with a 11.65% alcohol (v/v), reverse osmosis can provide two products: 6.85 and 12.85% alcohol (v/v).

Pervaporation

Pervaporation differs from other membrane processes in that the membrane constitutes a barrier between the feed in the liquid phase and the permeate in the gas phase. The driving force that is applied across the membrane creates a chemical potential gradient in the liquid phase, and the selectivity of the membrane is then the determining factor in the relative flow of the different components. In contrast to reverse osmosis, the osmotic pressure is not limiting, because the permeate is kept under low pressure.

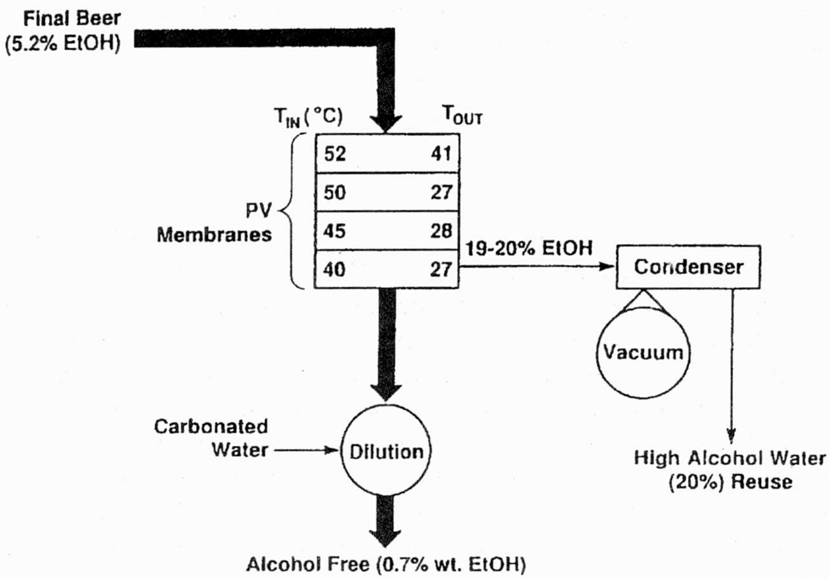

Fig. 4. Pervaporation process for alcohol reduction in beer (after Fleming and Slater, 1995)

The GFT is the best known commercial process allowing dealcoholisation of beers, wines, and liquors (Fleming and Slater, 1995). Polydimethyl silicone-type membranes have been used to reduce and to remove ethanol from various alcoholic beverages. As in the pilot-scale plant for beer in Figure 4 (Fleming and Slater, 1995), selective permeation of ethanol is straightforward and alcohol can easily be reduced to 0.7% wt. for alcohol-free beer. Reduction is currently limited to around 0.1% wt. because of membrane selectivity. Fusel oils (amyl and propyl alcohol fractions) can also be separated in the process and recovered. Depending on the choice of membrane, permeate quality can be controlled from 15 to 55% ethanol, so in many cases the permeate is a useful product. In the production of low-alcohol wines, for example, the permeate is useful as a salable brandy (Escudier et al., 1988).

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