MEMBRANE APPLICATIONS IN THE SUGAR INDUSTRY

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INTRODUCTION

A breakthrough of membrane technologies into most of the major industries has several important reasons. Drastic improvement of membrane materials has been made during the last 10-15 years. New environmental regulations impose additional requirements on conventional filtration processes resulting in increased cost of filter cake handling and disposal. Lower costs and an extended lifetime of the membranes are among the factors to be mentioned in this context. These and other factors make membrane technology applicable in the areas where it was not previously regarded feasible. Therefore, the time has come to reconsider replacement of conventional filtration and to develop the new applications for membrane separations.

The sugar industry is one of the few areas that membrane "explosion" has not reached. It is even more surprising taking into account that first research papers on membrane applications in sugar industry appeared in the early 1970's. R.F. Madsen [1] reported testing UF cellulose acetate membranes for beet sugar juices' purification and RO membranes for juice concentration. An idea of replacing conventional juice purification by membrane process fascinated sugar technologists for many years. Numerous efforts have been done to test the feasibility of the new processes [2,3,4]. W. K. Nielsen and his colleagues gave an extensive review and summary of these efforts in [5]. Variations in juice properties and analytical procedures shown in the papers of different authors make it difficult to conclude whether or not membranes can replace traditional processes. Information is available in the literature [6] on use of membranes for clarification and decolorization of cane syrups.

Several years ago a large-scale system utilizing ceramic membranes Kerasep was installed for ultrafiltration of clarified cane juice. Details on system parameters and operation can be found in the literature [7,8]. The system is no longer operational.

In the recent Sugar Processing Research Institute (SPRI) meetings membrane filtration occupied a significant place. We have analyzed the potential applications in the sugar cane and beet industries and emphasized importance of proper testing [9]. It is critical to realize the limitations of various membrane processes and their effect on components of technical sugar solutions. It is even more important to evaluate the indirect effect on membrane filtration on downstream unit operations such as crystallization and evaporation.

Extensive testing of membrane technology and increased cooperation between the industrial users and membrane suppliers allowed most problems reported in the earlier test programs to be overcome. The latest membranes can withstand high temperatures, harsh operating conditions and provide high quality permeate for further processing. The results of tests by the sugar companies together with various membrane suppliers in the cane and beet industries were reported in the following recent publications: Alvarez,e.a. [26], Kochergin [9], McArdle, e.a [18], Wittwer [27]. Steindl [28] has performed an excellent analysis of the status of membrane filtration in the cane industry.

The purpose of this paper is to review possible applications for membrane technology in sugar industry based on the analysis of sugar processing technology and recent experimental results. Applications where micro- or ultrafiltration processes are used as a pretreatment of feed to chromatographic separation will be discussed.

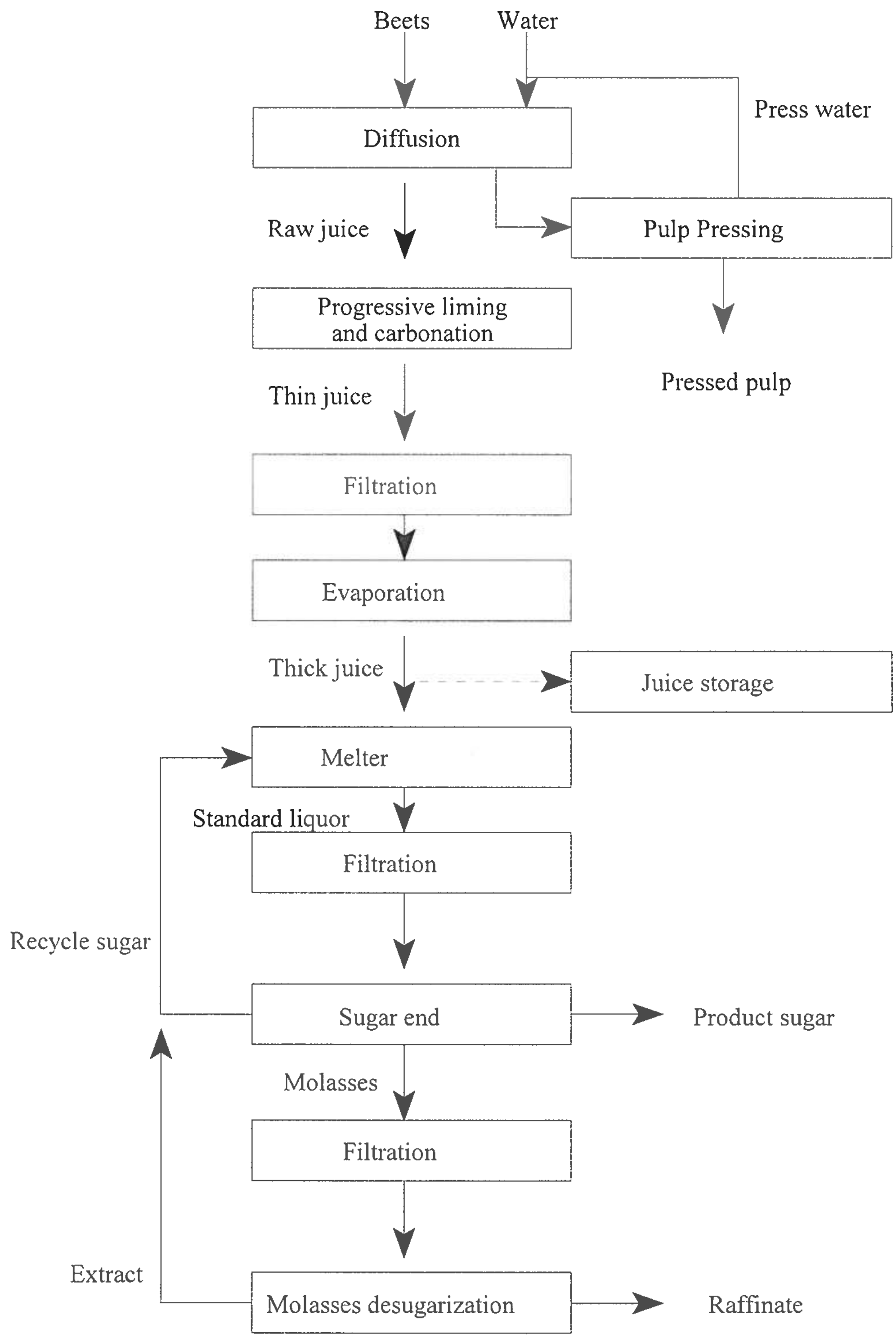
Beet sugar process description

A simplified block diagram in Figure 1 illustrates main steps of beet sugar processing with emphasis on filtration stages. It also introduces the sugar terminology that will be used in the paper. A comprehensive review of sugar beet and cane technology may be found in the handbooks [11,12]. Cane sugar mills do not use any filtration processes. Suspended solids removal is achieved by various combinations of precipitation, flotation and screening processes. Filtration step is applied for suspended solids removal from solutions of attenuated raw sugars in the refineries.

It is interesting to mention that all sugar beet factories worldwide use the same principle of juice purification with many modifications. Normally raw sugar juice is treated with the "milk of lime" (water solution of a calcium hydroxide). The liming step is usually followed by carbonation to precipitate calcium carbonate along with calcium salts of organic acids, coagulated proteins, pectins, colloids and suspended particles. The purpose of this purification is to remove both suspended and part of the dissolved non-sugar components to increase sugar quality and overall factory "extraction" (common term equivalent to a product yield). Due to the limited amount of non-sugars that can theoretically be removed by liming and carbonation efficiency of juice purification generally does not exceed 25-35%. Because of that juice purity is usually increased by 2-4 points. Juice purity is defined as percent of sucrose based on DS. Purified thin juice is then evaporated to about 70% DS. Resulting thick juice is a feed material for subsequent crystallization. Some factories with undersized sugar end store a portion of thick juice during slicing campaign and process it later. Thick juice is usually filtered prior to storage to reduce bacterial count.

White sugar is produced in the first evaporative crystallization step. Crystallization of the mother liquor does not yield sugar of product quality. Therefore, lower grade sugar is continuously recycled and mixed with thick juice to form standard liquor. Due to a significant amount of non-sugars present in syrups recycle flow of sugars may reach 70-80% of a feed stream. Since the mother liquor after last crystallization (molasses) contains about 8-10% of total sugar entering the factory most of the U.S. and several European companies use chromatographic separation process to obtain enriched sugar fraction (extract) and non-sugar fraction (raffinate). Industrial chromatography of molasses proved to be an extremely efficient unit operation provided that suspended solids are completely removed from the feed materials.

FIGURE 1
Block Diagram of Beet Sugar Process



Specific features of sugar industry applications

Applications in the sugar industry impose specific requirements on membrane characteristics. The parameters affecting membrane performance and durability are discussed below.

Temperature

Most sugar solutions should be filtered at the highest possible temperature to reduce viscosity and prevent bacterial growth on the feed side of the membrane. It is not recommended to keep the sugar solution below 80°C for extended periods of time. Most of the tests reported recently in the literature are performed at 85-95°C, which presents a challenge for polymeric membrane manufacturers.

Characteristics of suspended solids

The concentration of suspended solids in the beet juice depending on the pretreatment may be up to 1-2% wt. Suspended solids content in cane clarified juice varies in different locations from 10 to 300 ppm, certain samples of cane C-molasses may contain up to 5-7% of suspended solids. The quality and shape of suspended solids is also important.

The main characteristic of suspended solids is an extremely wide particle size distribution. We have found that for raw beet and clarified cane juices about 50% of particles are smaller than 1-2 micron. The sensitivity of our particle size analyzer does not let us observe the size distribution in the submicron range. The large particles may be several millimeters in diameter. It is interesting to observe the difference between the number and volume particle size distribution. For example, the measurement of volume size distribution for a sample of cane clarified juice showed only 5% below 2 micron in size, the number distribution showed 50% below 2 micron. This indicates that the overall particle size distribution is quite wide and a few large particles can make a significant difference in the results. Fibrous material is also present in raw juice and clarified juices which may create problems for some types of membranes.

Presence of abrasive particles

In the beet factories and cane mills the feed material comes from the field and usually contains a certain amount of silica and sand. Although most of it is removed in the washing and clarification steps, residual amounts are still present in the solution. Being concentrated in the feed loop at high crossflow velocities, these particles may create a danger of membrane surface abrasion. In the pretreated raw beet juice the concentration of acid insoluble material may reach as high as 20-30% of total suspended solids.

Sugar losses

High concentration factors are required to minimize sugar losses in the retentate streams. It is not uncommon to operate a membrane system at concentration factors of 50 to 100 and use diafiltration or other desugarizing process on the remaining stream. Pilot testing of membrane performance within a wide range of concentration factors presents some special challenges. It may take a specially designed concentrate control manifold to handle the wide range of flowrates. Sometimes a full operation cycle is required to reach equilibrium at high concentration factors, therefore multistage installations may be used for pilot testing.

High flux

In most applications the streams ranging from 1000 to 5000 gallons per minute will be filtered through membranes. Rather high permeate flux is desirable to justify the investment. Fluxes ranging from 50 to 400 LMH (liters/m^2/hour) are reported for various membranes and concentration factors. At first glance these fluxes may not be considered very high, but in combination with the required high concentration factors they are quite significant.

Various composition of feed

Composition of the solution and suspended solids content in the feed material may vary significantly during the operating season. It is typical to see increased dextran levels in the raw juice towards the end of the beet slicing campaign. A similar effect can be observed in the clarified juice in cane mills during rainy harvest conditions. The quality of refinery syrups also varies depending on the composition of processed raw sugars. The content and quality of suspended solids also changes depending on efficiency of pretreatment operations.

Unstable feed material

It is important to realize that industrial sugar solutions are quite unstable. Significant sugar losses may be experienced if solutions are stored for more than one or two hours due to bacterial or other mechanisms of degradation. The fact that permeate is usually sterile does not mean that sucrose will remain safe in the feed loop or tanks. Potential color formation is another factor that is related to excessive storage.

Potential Membrane Applications

Possible applications for membrane technology in beet and cane sugar industry can be conditionally divided in two groups: replacement of conventional filtration processes and the new developments. Each potential membrane process will need to go through a development stage and subsequent economic evaluation. Replacement of traditional filtration is still difficult to justify but the new projects may become more feasible with the increased requirements on handling of waste filter-aid. Particularly, cost of the equipment necessary to dewater filter-aid sludge in some applications may be comparable to the cost of a membrane system. This will make membrane technology look more attractive to sugar technologists.

Group 1

1. Standard liquor filtration (some companies apply two-stage conventional filtration). Process will eliminate filter-aid usage and disposal but still requires appropriate concentrate handling process to reduce sugar loss. Low flux is expected due to high concentration of dissolved solids (about 70% DS).

2. Some factories store thick juice during slicing campaign and process it later in the season. Thick juice is normally filtered prior to storage to reduce bacterial counts. Juice sterilization by microfiltration can significantly reduce storage losses.

3. Molasses desugarization systems in beet industry are very sensitive to presence of suspended solids in the feed streams. Micro- or ultrafiltration can be extremely efficient for this application. Molasses streams should be filtered at 50-60% DS.

4. Cane molasses pretreatment prior to chromatography should be developed on case to case basis due to tremendous differences in molasses properties from various sources.

5. Press water is a very diluted stream containing about 3-4% of total sugar entering the factory. It is normally recycled back to a diffusion stage after pulp presses. Microfiltration process can be applied for both press water sterilization and suspended solids removal.

Group 2

1. Raw juice microfiltration or ultrafiltration is a part of pretreatment prior to chromatographic separation according to the process patented by The Amalgamated Sugar Company [12]. Pretreated and filtered raw juice is softened and evaporated. Resulting syrup is purified using chromatographic separation. Details about the process can be found in the paper by M. Kearney and D. E. Rearick [13].

2. The same approach like the one referenced in paragraph one is currently being developed to cane juice purification. It had been that chromatography was capable of removal cane non-sugars and color very efficiently. Membrane pretreatment is necessary prior to feeding juice to a resin bed. The results show that very high quality white sugar can be manufactured as a result of this process [15].

3. Raw juice ultrafiltration as a replacement to conventional purification method is still difficult to justify as a stand-alone process. Permeate is more likely to be post-treated with lime to achieve a purity increase comparable to liming and carbonation.

4. Microfiltered raw juice can be stored and processed later. After appropriate testing the process may be useful for factories with lime kilns undersized to handle an increased slice rate. Additional slice rate may be achieved by extending the campaign length keeping the lime kiln capacity at the same level.

5. Micro/ultrafiltration of mixed or clarified cane juice followed by decolorization [16] will remove high molecular weight materials. Feasibility of this process should be carefully studied since adsorption does not reduce amount of monovalent cations and invert sugars in the solution which comprise a major portion of non-sugars in the juice stream.

6. Cane juice color may be reduced by UF in the cane mills and refineries [17].

7. A paper presented by R. Kwok at Sugar Processing Research Institute gives detailed description of a membrane application for ultrafiltration of clarified cane juice. After two years of operation the membrane filtration was still in the development phase with estimated return on investment of about 8% [7]. Koch's latest reports are very encouraging about potential application of high-temperature spirals for cane applications [18].

New ideas on membrane applications continue to appear on a daily basis when new information on membrane performance becomes available. Setting priorities overall is difficult due to the differences in companies' strategic planning. Priorities are significantly affected by new EPA regulations, cost of power and membrane systems.

Raw juice purification using simulated moving bed chromatography

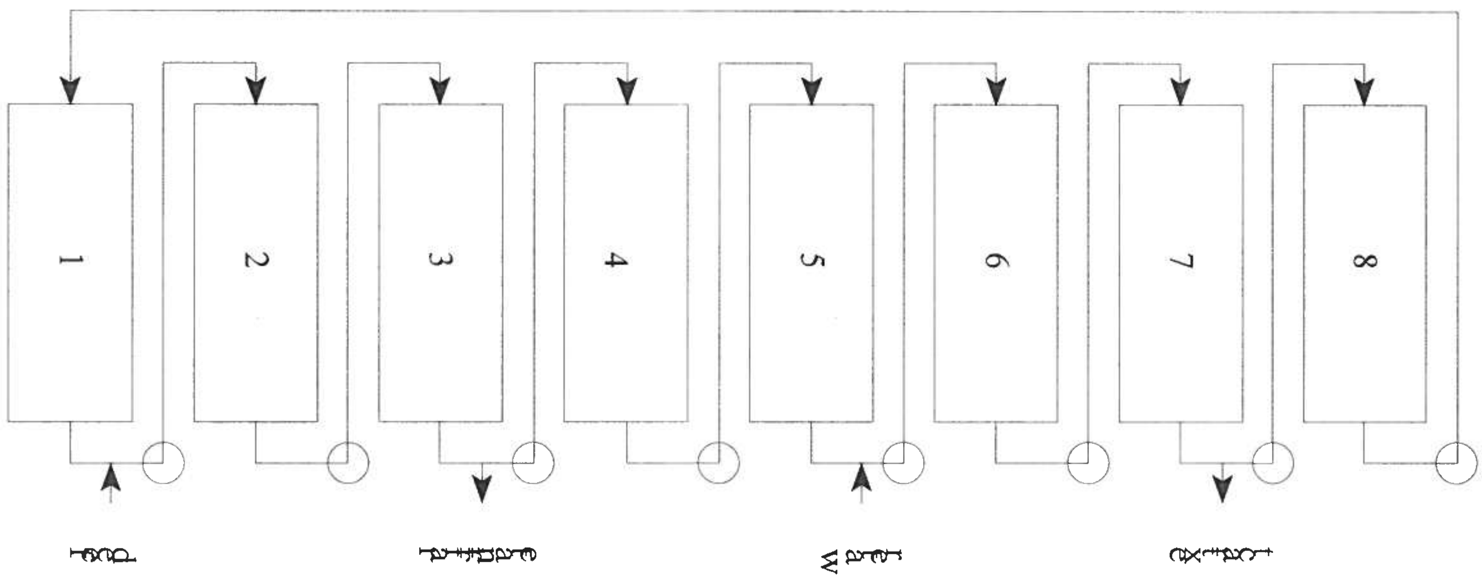
Chromatographic separation of raw beet or cane juice provides a new opportunity for membrane application since it does not require any juice purity increase across membrane. Normally one would expect a small purity rise across the membrane when UF or NF membranes are used. Unfortunately high separation efficiency is accompanied by low fluxes. Conventional purification processes can remove only 25-35% of total non-sugars whereas the chromatographic separators remove about 85% of non-sugars and color. Most of these non-sugars (e.g., monovalent ions) are considered "non-removable" by conventional methods. The separation that is difficult or impossible to achieve using membrane technology can be easily accomplished with ion exclusion chromatography.

Most existing industrial chromatography applications use the simulated moving bed (SMB) principle [19,20]. An SMB system usually comprises one or several columns filled with separation medium, e.g., ion-exchange resins in separation of sugars. In SMB process feed stock and eluent are continuously added to the system. At the same time extract and raffinate streams are continuously removed from the separator. The points of feed and eluent introduction and products withdrawal are switched periodically simulating countercurrent movement of separation media. By varying the ratio between product fractions it is possible to build up an internal component inventory inside the system. Most importantly only fractions of the inventory are removed as products. The rest of components keep recirculating inside a closed loop. A principle flow diagram of an SMB process with eight cells is shown in Figure 2. Due to multi-pass nature of SMB processes higher product purity and recovery can be achieved [21].

Continuous recirculation of components inside SMB system imposes strict requirements on suspended solids elimination out of feed streams. Backwashing of separator cells is

FIGURE 2

FLOW DIAGRAM OF AN EIGHT-CELL CHROMATOGRAPHIC SEPARATOR



considered as an emergency mode of operation rather than a routine procedure. Raw beet and cane juice contain a very wide spectrum of suspended solids ranging in size from a fraction of a micron to several millimeters. Conventional processes can easily remove the coarser particles but only membrane technology may be a viable option for removal of submicron particles. Juice sterilization as a side effect of membrane filtration is expected to benefit downstream operation.

Review of membrane performance

Although membrane separation characteristics strongly depend on the average pore size, the mechanism of separation is much more complicated than simple "screening". Formation of a dynamic layer, concentration of dissolved and suspended solids and presence of surfactants are among the factors critical for membrane performance. According to traditional classification membranes are rated by pore size in the microfiltration range and by "molecular weight cut-off" (MWCO) in ultrafiltration.

Analysis of the composition of various sugar juices and syrups is very helpful in evaluating expected membrane performance. Although only experimental results can provide the true information on membrane performance, preliminary analysis may save time and resources for a test program and provide information on the nature of potential foulants.

Table 1 contains analytical data for a sample of beet diffusion juice from a factory in Southern Idaho, USA. A simple comparison of molecular size of juice constituents with pore size of membranes shows that most of the high molecular weight components (molecular weight exceeding several hundred thousand units) can be removed by microfiltration or "loose" ultrafiltration membranes. Because of the larger porosity higher permeate flux is expected in this range of pore sizes. Using membranes with smaller pore size causes significant flux reduction without noticeable increase in separation.

Based on preliminary analysis of juice properties it may be concluded that membranes may be feasible for the removal of suspended solids, colloidal material and other high molecular weight compounds, but they perform poorly for separation of most of the dissolved non-sugar components.

Conventional purification methods in beet factories typically eliminate about 30% of non-sugars which translates into 3.0-3.5 points purity increase. Analysis of data in Tables 2 and 3 can give an answer to the long-debated question whether the membrane filtration can achieve the degree of purification comparable with conventional methods. Table 2 contains calculated numbers of purity increase corresponding to different levels of non-sugar removal for an 88 purity juice sample. Under the assumption that one half of the unaccounted non-sugars in Table 1 is rejected by ultrafiltration membranes, maximal theoretical non-sugar elimination can not exceed approximately 10%. The purity difference between the feed juice and permeate increases with decrease in feed juice purity at the same degree of non-sugar elimination. Expected values of purity rise across a membrane are listed in Table 3 assuming 10% non-sugar elimination. Therefore, expected purity change across MF or UF membrane should not exceed more than one

Table 1
Typical Analysis of Beet Diffusion Juice (Southern Idaho)

Component	Concentration		Molecular weight
	% on DS	% on non-sugars	
Sucrose	87.75	N/A	342
Invert sugars	1.03	8.59	180
Raffinose	0.42	3.5	595
Betaine	0.31	2.58	117
Citric acid	0.73	6.09	210
Malic acid	0.36	3.00	134
Lactic acid	0.12	1.00	91
Acetic acid	0.25	2.08	60
Oxalic acid	0.29	2.38	126
Other organic acids	0.20	1.67	--
Calcium, Magnesium	0.35	2.92	24-41
Sodium, Potassium	2.01	16.76	23-40
Inorganic anions (chloride, sulphate, nitrate, etc.)	2.97	24.76	less than 100
Proteins	**	--	15,000-100,000
Colorants	**	--	10,000-1,000,000
Dextrans	0.3	2.50	50,000-2,000,000
Pectins	**	--	20,000-400,000
Glutamine*	0.7	5.84	146
Other amino acids*	0.7	5.84	100-300
Unaccounted non-sugars	1.26	10.50	--
Total non-sucrose	12.00	100.00	--
Total solids	100.00		--

- Concentration of glutamine and amino acids is calculated based on molasses content of about 9% on non-sugars.

** Information was not available.

*** Calcium and magnesium are calculated based on hardness level of 12 meq/100 DS.

Table 2
Juice purity increase as a function of non-sugar elimination

Juice purity	88	
Non-sugars, % DS	12	
Non-Sugar Elimination, %	**Permeate Purity, %**	**Purity Increase, Points**
5	88.53	0.53
10	89.07	1.07
15	89.61	1.61
20	90.16	2.16
25	90.72	2.72
30	91.29	3.29
35	91.86	3.86
40	92.44	4.44
45	93.02	5.02

Table 3
Expected purity increase at 10 % non-sugar removal

Juice Purity	82	83	84	85	86	87	88	89	90
Purity rise @ 10% NS elimination	1.50	1.44	1.37	1.29	1.22	1.15	1.07	0.99	0.91

purity point (may be slightly higher for low purity juices). This conclusion is confirmed by the experimental data obtained by various researchers. Most of the data in Table 4 correspond well with the theoretical analysis.

Table 4
Experimental data on purity and color changes across the MF and UF membranes

Feed Material	Membrane Pore Size	Change Across Membrane		Reference Number
		Purity increase, points	Color decrease, %	
Cane clarified juice	300 kD		10-15	(7)
	6-20 kD	0.3-1.3	30-40	(5)
	0.05 micron	1.5		(24)
Cane molasses	0.2 micron	0.3-0.8		(25)
Affination syrup	15 kD	1.2	40	(23)
	300 kD	0.6	21	
	0.1 micron	0.6	7	
Beet raw juice	15 kD	1.5		(4)
	15 kD	1.7		(3)
	20 kD	2.5-4.0		(5)
	0.2 micron	0.2-0.4	**40-50	(25)
Beet molasses	0.2 micron	0.3	40	(25)
Press water	0.2 micron	0		(25)

* kD=kiloDaltons, characterizes molecular weight cutoff (MWCO), e.g. 10 kD-10,000 MWCO
** Only for highly colored samples

It is also important to analyze the influence of membrane filtration on other parameters critical for various processing steps. Color of sugar syrups is definitely one of the most important factors affecting the sugar end operation and properties of product sugar. A number of studies have shown that depending on molecular weight colorants in sugar juices have different effects on product quality. Therefore, changes in color across the membrane affect crystallization both directly by reducing color of the solution and indirectly by eliminating high molecular weight colorants. The latter appears to have significant effect on sugar quality especially in cane applications. Table 4 contains some information on color removal from various technical sugar solutions. Although some of the data show influence of membrane size on efficiency of color removal, separate evaluation should be done for each application at different stages of processing.

Table 5
List of Membrane Manufacturers

Membrane Type	Material	Manufacturers
Spiral wound	Polymeric	Koch, Osmonics
Hollow Fiber	Polymeric	X-Flow
Monolith	Ceramic	US Filter, Rhône-Poulenc, CeraMem, Fairey
Tubular	Polymeric	Koch, PCI
Tubular	Carbon	Koch
Tubular	Stainless steel/ceramic	Graver, Pall
Vibrating disk	Polymeric	Pall

Removal of dextrans is critical in both cane and beet sugar manufacturing. According to many sources [22] dextrans not only change the purity of sucrose crystals but also affect crystal morphology. The long chain dextrans present in sugar juices which are believed to cause problems during the crystallization step typically have molecular weight about 2 to 20 MD. These dextrans are definitely rejected by both MF and UF membranes. Various researchers report different levels of dextran elimination across the membranes. The discrepancies obviously depend on the analytical method used. Typically, the haze method accounting for high molecular weight dextrans shows higher values of dextran elimination. A method developed by E. J. Roberts covering a wider range of molecular weights appears to be more accurate and indicates that low molecular weight dextrans are not rejected by the MF and UF membranes.

Main goals of test program

A list of membranes tested for the last few years in the sugar industry applications along with the list of manufacturers active in their development efforts is provided in Table 5. This list is not complete but it covers a wide range of membrane types and materials.

It is important to realize that permeate quality, membrane performance and cleaning procedures are usually satisfactory for most of the membranes tested. Therefore, selection of the most economical and reliable membranes becomes a focus of the research efforts.

The integrity of the membranes and modules, reproducibility of membrane performance and consistency of cleaning procedures should be thoroughly tested as a part of a well designed test program. We have emphasized in our previous paper that such extensive testing can only be accomplished in a long-term testing program. An average size industrial installation for beet or cane industry may comprise several thousand square meters of membrane surface. Depending on the type of membrane this may translate into hundreds of modules combined in parallel and in series.

There is a possibility that one type of membrane will not satisfy the requirements of a new process. For example, it is well known that spiral membranes usually have a limit on the amount and quality of suspended solids. On the other hand they are the most compact (high surface-to-volume ratio) and comparatively inexpensive. In certain sugar applications, where achieving high concentration factors is critical a hybrid system should be considered. For example, the major portion of a stream will be treated through the spiral membranes and the concentrate out of the system will be filtered through membranes with larger feed channels, such as tubular type.

Troubleshooting

An important part of the learning experience when conducting a test program is troubleshooting of the pilot installation. This provides valuable information for future operator training and early determination of problems in the industrial installations. Although only destructive methods of analysis give the final answer about the membrane conditions, proper data collection and analysis of operating parameters may give some indications of potential trouble. Several examples are discussed below.

Several basic control philosophies are used for operation of membrane installations. Some are based on maintaining constant transmembrane pressure (TMP), whereas the permeate flux continuously declines as the membrane fouls. This method allows permeate flux and hence feed flow fluctuation within certain limits. This requires additional capacity of supply and product tanks. Since sugar solutions are generally unstable, minimization of overall holdup volume becomes very important. We recommend an alternative control strategy that allows maintaining constant permeate flow, while TMP changes within predetermined limits. This strategy can be realized through increasing pressure of feed pumps or releasing the backpressure on the permeate side. The normal pressure and flow changes during one operating cycle (between subsequent cleanings) is illustrated in Figure 3. The TMP will gradually rise because of membrane fouling.

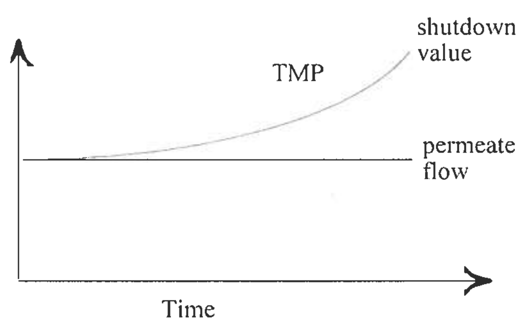


Figure 3. Normal Operation

We found it extremely important to monitor both flow and pressure in the recirculation loop at least in the pilot installations. These data provide valuable information about possible feed channel plugging. The recirculation flow should be maintained constant either with a variable frequency drive or a control valve.

Figure 4 illustrates the case when TMP increases as a result of partial channel blockage. Without monitoring the pressure drop on the feed side, erroneous conclusions may be made about premature membrane fouling. Drastic changes in pressure drop or TMP as well as sudden changes in membrane performance or cloudy permeate provide a clear indication of membrane catastrophic failure.

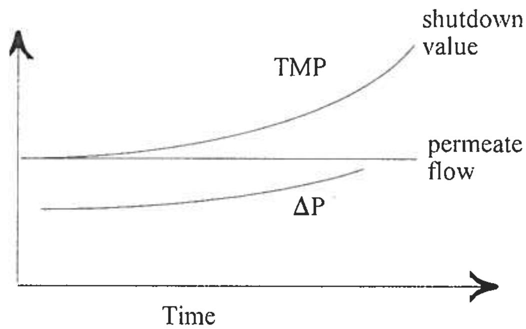


Figure 4. TMP increase because of feed channel blockage (no true fouling)

Monitoring of feed side pressure drop also may provide information on gradual buildup of suspended solids in the feed channels (Figure 5). During an operation cycle there is a natural increase in pressure drop when the system reaches equilibrium at a certain concentration factor. However, a gradual increase in pressure drop after several consecutive cleanings implies that there may be a problem with accumulation of solids in the feed channels.

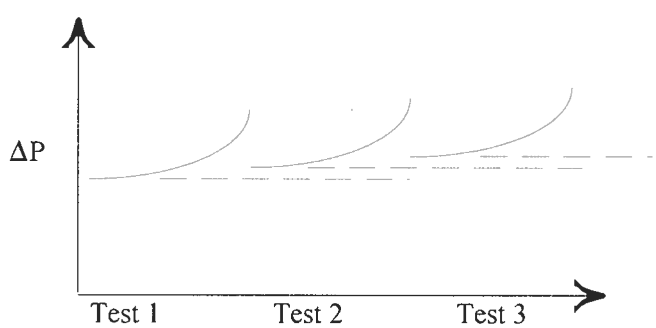


Figure 5. Gradual feed channel plugging

One of potential failure modes during long-term operation may be abrasion of the membrane surface. Typical changes in membrane performance are shown in Figure 4. Gradual removal of the tight membrane layer due to abrasion results in increased water flux along with increased fouling and shortening of operating cycles on a process stream.

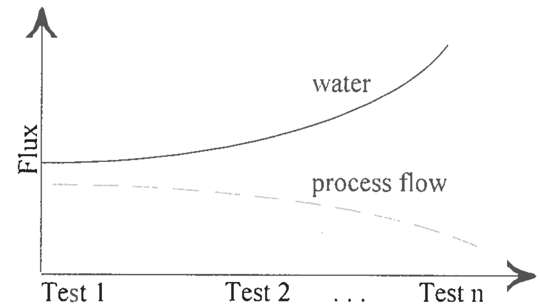


Figure 6. Abrasion of membrane surface

A slow performance decline over a long period of time is considered normal for some membranes especially with relatively short (one or two campaigns) service life. The first indication of such behavior is a decline in both process and water flux (Figure 7). If this problem is due to improper cleaning it may be corrected by establishing better cleaning procedures. If the problem persists, it may indicate irreversible fouling, membrane aging or compaction.

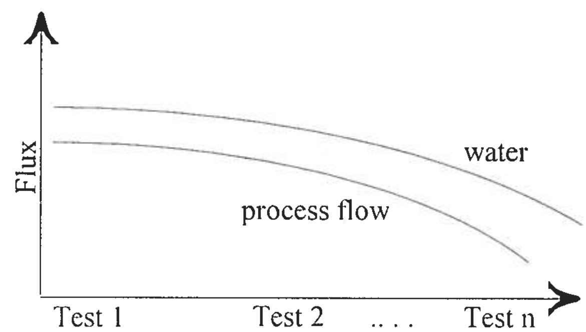


Figure 7. Performance decline due to membrane aging

Depending on the configuration of the test plant and the cleaning regime there is a possibility of bacterial growth on the permeate side of the membrane. Such conditions should be diagnosed and eliminated before constructing an industrial installation.

Reliability of industrial operation

One of the often-overlooked factors in the membrane process development is reliability of industrial operation. Sometimes the membrane manufacturers are not aware of the process problems that may potentially cause membrane system shutdown, therefore necessary safety measures are outside of their scope of supply. It becomes the responsibility of the sugar company to analyze the process and find out the process changes potentially detrimental for membrane performance. A typical example would be excessive use of defoaming agents that are known to significantly reduce membrane performance. In such a case serious capacity reduction should be expected.

However, the most serious problems may be caused by sudden catastrophic failure of a large portion of the membrane system. The upstream process fluctuations causing such failures should be reviewed with the manufacturer and special precautions should be taken. For example, if spiral membranes are sensitive to the presence of fibrous material plugging the feed channel, the installation of an additional double screening system may be prudent. In case of sensitivity of the membrane material to pH fluctuations the cleaning agent supply system should be properly automated. Special procedures should be developed to provide a "fool-proof" operation. Another example is ceramic membranes that are generally sensitive to sudden temperature or pressure fluctuations. Special alarms and shutdowns should be built in the systems to absolutely eliminate such accidents.

Such safety measures may become quite costly, therefore, they should be included as a part of feasibility studies. Factors such as material and labor requirements for membrane replacement should also be considered. Ideally it would be convenient to install a new system in parallel with the old processing scheme to be able to have a backup in case of unexpected problems. However, very few companies may have this luxury. Because of the large size of membrane systems, it is important to deal with a large membrane manufacturer capable of providing required replacement quantities on a short notice. The cost of factory shutdown is not likely to be covered by membrane warranty. Keeping replacement membranes in stock may be another, but costly option.

Organization of a test program.

The organization and coordination of extensive test programs is quite expensive. It also requires a staff of technical specialists dedicated to carry on with a project for a full processing season. Reliable and highly automated equipment and analytical support are among the factors critical for success of a project. Very few companies especially in the USA can afford such programs on their own. However, the development of new processes is crucial for long-term industry survival.

We believe that organization of study groups involving several companies with common interests may help to resolve this issue. It certainly becomes a challenge for participating sugar companies to find a compromise between the competition and detailed continuous development of strategically important technologies. It is advantageous for such study groups not to be affiliated with a single manufacturer to be able to evaluate several competitive products. Another benefit of a strong study group is that it attracts membrane manufacturers interested in the development of new sugar applications, which makes the alliance more efficient.

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