

MEMBRANE FILTRATION OF CLARIFIED JUICE

By

R.J. STEINDL and D.W. RACKEMANN

Sugar Research and Innovation, Queensland University of Technology, Australia

r.steindl@qut.edu.au

**KEYWORDS: Membrane Filtration,
Ceramic, Polymeric, Flux, Fouling.**

Abstract

A MEMBRANE filtration plant using suitable micro or ultra-filtration membranes has the potential to significantly increase pan stage capacity and improve sugar quality. Previous investigations by SRI and others have shown that membranes will remove polysaccharides, turbidity and colloidal impurities and result in lower viscosity syrups and molasses. However, the conclusion from those investigations was that membrane filtration was not economically viable. A comprehensive assessment of current generation membrane technology was undertaken by SRI. With the aid of two pilot plants provided by Applexion and Koch Membrane Systems, extensive trials were conducted at an Australian factory using clarified juice at 80–98°C as feed to each pilot plant. Conditions were varied during the trials to examine the effect of a range of operating parameters on the filtering characteristics of each of the membranes. These parameters included feed temperature and pressure, flow velocity, soluble solids and impurity concentrations. The data were then combined to develop models to predict the filtration rate (or flux) that could be expected for nominated operating conditions. The models demonstrated very good agreement with the data collected during the trials. The trials also identified those membranes that provided the highest flux levels per unit area of membrane surface for a nominated set of conditions. Cleaning procedures were developed that ensured the water flux level was recovered following a clean-in-place process. Bulk samples of clarified juice and membrane filtered juice from each pilot were evaporated to syrup to quantify the gain in pan stage productivity that results from the removal of high molecular weight impurities by membrane filtration. The results are in general agreement with those published by other research groups.

Introduction

The sugar industry has long maintained an interest in the application of membrane filtration for both quality improvements and as a pre-treatment for processes to produce value-added products. Since the early work of Madsen (1973), sugar industry research organisations, commercial manufacturing and membrane supplying companies and sugar milling companies have been actively involved in the assessment of the benefits of membrane filtration systems and the installation and development of pilot plants into sugar factories.

Steindl (2001) provided a summary of available data from investigations undertaken at a number of sites around the world. Those investigations concluded that membranes would remove polysaccharides, turbidity and colloidal impurities and result in lower viscosity syrups and molasses, provide higher growth rates and improve exhaustion. The consensus from previous investigations undertaken in Australia was that membrane filtration was not economically viable due to high capital and operating costs. However, any economic analysis has to be based on the economic environment under which a particular factory is operating and the reasons why the installation of a membrane plant is being considered.

Despite the extensive investigations, the only two industrial installations of membrane technology in the cane sugar industry have occurred at Puunene Mill in Hawaii (Kwok *et al.*, 1996) and at Felixton Mill, South Africa (Jensen *et al.*, 2006).

This paper describes the recent assessment of current generation membranes undertaken by SRI.

Membrane trials

A comprehensive assessment of current generation membranes was undertaken by SRI using two pilot plants and ceramic tubular membranes provided by Applexion and spiral wound polymeric membranes provided by Applexion and Koch Membrane Systems (KMS). The assessment focused on the processing of clarified juice under a range of operating conditions to determine (a) the long-term sustainable flux levels and concentration factors that are possible for the different membrane configurations; and (b) improvements in juice quality and the derived downstream benefits. Suitable clean-in-place procedures were also examined using supplier recommended chemicals to maintain flux levels.

Bulk samples of clarified juice and membrane filtered juice were evaporated to syrup to assess the effects on pan stage productivity. The evaporated syrup was used in a laboratory vacuum pan to estimate changes in pan productivity and sugar quality improvements that could be achieved from membrane filtered juice.

Membrane pilot plants

Two pilot plants provided by Applexion and KMS were installed at an Australian mill for the trials. Schematics of the pilot plants are shown in Figures 1 and 2. Both plants contain (a) pre-filters fitted with 100 μm screens, (b) feed and recirculation pumps (c) feed buffer tank, (d) membrane modules (e) heat exchanger with thermostatically controlled valve and instrumentation.

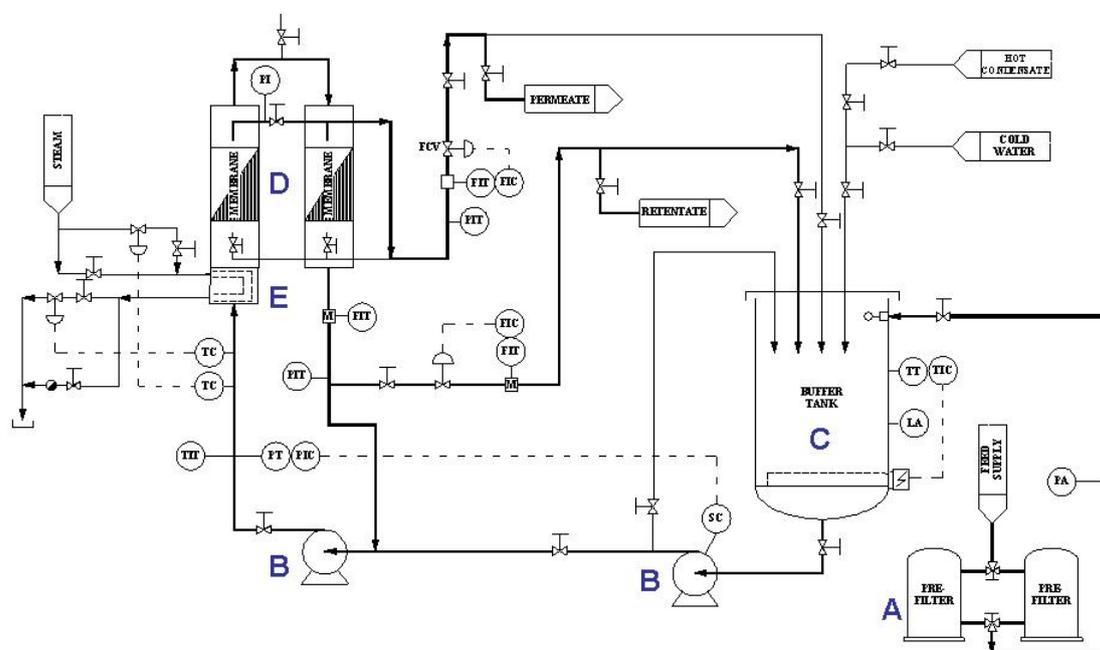


Fig. 1—Schematic of the Applexion pilot plant (A - pre-filters; B - feed and recirculation pumps; C - feed buffer tank; D - membrane modules; and E - heat exchanger).

Both pilot plants were operated in a ‘feed and bleed’ mode. The Applexion unit operated by controlling the transverse membrane pressure (TMP) to maintain a relatively constant volumetric concentration factor (VCF) and permeate flux. TMP is defined as the force which drives liquid flow

through a cross flow membrane and equals the average of the feed and retentate pressures less the permeate pressure. The VCF is defined as the ratio of the volumetric flow rate of feed to the volumetric bleed rate of retentate in a continuous filtration system.

The retentate flow was adjusted using a pressure valve to control the VCF. The VCF was maintained by increasing the TMP (to a limit of 4 bar) to maintain the permeate rate as the membranes fouled. The KMS unit maintained a constant pressure drop between the feed inlet and the retentate outlet of the membrane modules for the duration of the run. This meant that, as the membranes fouled, the permeate flow slowly decreased.

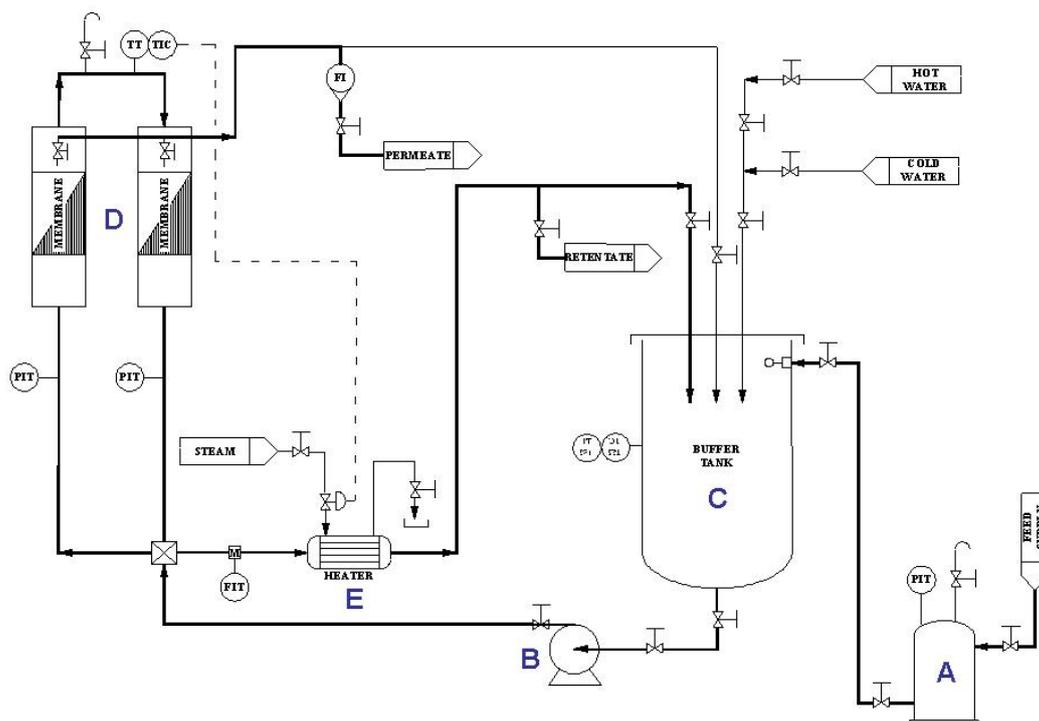


Fig. 2—Schematic of the KMS pilot unit (A – pre-filter; B - feed pump; C - feed buffer tank; D – membrane modules; and E – heat exchanger).

Applexion provided several ceramic membranes to enable the investigation of the effects of the various flow channel configurations. KMS provided two spiral wound membranes including the sugar spiral (SS) and high yield sugar spiral (HYSS) that had never been applied to clarified juice applications previously. Both spiral membranes could be operated continuously on feed juice at 95°C. The polymeric membranes supplied by Applexion had lower operating temperature limits compared to the KMS membranes.

Details of the membranes investigated including the nominal molecular weight cut off (MWCO) or pore sizes and the filtration area of each membrane module are given in Table 1. Photographs of end views of some of the membranes are shown in Figures 3 and 4.

Trials were conducted using both pilots with clarified juice to assess membrane performance under a wide range of operating conditions including:

Temperature:	80 to 97°C
Recirculation flow velocity (Applexion):	3.9 to 5.2 m/s
Pressure drop (KMS - SS):	275 kPa
Pressure drop (KMS - HYSS):	415 kPa
VCF:	2 to 10X.

Table 1—Details of the membranes tested during the trials.

Membrane reference code	Membrane format	MWCO or pore size	Flow channel diameter, mm	Total surface area, m ²
Membranes supplied by Applexion				
IXP050F 4040	Spiral organic	50 kDa	n.a.	3.8
IXP150F 4040	Spiral organic	150 kDa	n.a.	3.8
EW 4040	Spiral organic	90 kDa	n.a.	6.5
JX 3840C	Spiral organic	0.3 µm	n.a.	5.5
KB-W-07 (300)	Ceramic	300 kDa	3.5	3.44
KB-W-07 (01)	Ceramic	0.1 µm	3.5	3.44
KB-T	Ceramic	0.1 µm	2.6	4.90
KB-W-T (045)	Ceramic	0.45 µm	3.5	3.44
KB-X	Ceramic	0.1 µm	6.0	2.16
Membranes supplied by KMS				
KMS - SS	Spiral organic	50 kDa	N/A	7.25
KMS - HYSS	Spiral organic	50 kDa	N/A	5.00

**KB-W-07****KB-X****KB-T**

Fig. 3—End views of three of the ceramic membranes provided by Applexion.

**KMS-SS****KMS-HYSS**

Fig. 4—End views of the spiral organic membranes supplied by KMS,

Analyses

Daily composited samples of clarified juice feed, permeates and retentate were collected for analysis of sucrose, brix, starch, dextran, total polysaccharides and colour using standard ICUMSA methods. Snap samples of feed and permeate were also collected every three hours for analysis of brix, pH and turbidity (absorbance at 900 nm). Bulk samples of clarified juice and membrane

filtered juice from each pilot were evaporated to syrup in the laboratory to assess the effects on pan stage productivity. Sugar was then produced using the SRI laboratory vacuum pan under defined conditions and procedures to provide predictions of overall growth rate changes and pan stage productivity changes. The sugar produced in the laboratory pan was analysed to determine the sugar quality improvements that could be achieved after membrane filtration of the clarified juice.

The crystal growth rates were measured using the method developed by Broadfoot and Steindl (1980). The procedure was designed to measure growth rates under constant conditions of supersaturation and temperature for each growth experiment. Variations in growth rate would then be a function of viscosity and impurities in the mother liquor. The solubility coefficient of the syrup was determined by analysing the saturated syrup used for the growth rate experiments and calculating the solubility coefficient from the sucrose/water ratio. Viscosities were measured with a Brookfield viscometer and a No. 2 spindle at 67°C.

Cleaning procedures

Water flux levels were measured before, during and after cleaning procedures. The pre-trial water flux was used as a reference to gauge the effectiveness of the cleaning procedure and the chemicals used.

The membranes were cleaned in place (CIP) during the factory trials using the CIP recommendation of the membrane suppliers. For the Applexion pilot plant a cleaning cycle was initiated when the maximum TMP was reached and the flux started to decline. A cleaning cycle was initiated for the KMS pilot when the permeate flux had declined below a pre-set limit (around 50–60 L/m².h).

The hottest clean water available (~85°C) was used to flush the chemicals and rinse the membranes.

Results

The results of the membrane trials are presented for each pilot plant separately because of the different operating conditions. The trials were conducted over two crushing seasons but only average data are presented for the more promising membrane configurations.

Filtration rate

The obtainable flux through a membrane is not only dependent on the liquid properties and the type of membrane system used but also on the operating parameters and conditions. Basically, there is pressure controlled and mass transfer controlled regions for filtration according to Cheryan (1986). Flux is dependent and can be improved by a number of factors influencing these regions such as:

- Increasing operating pressure, as this influences the permeability through the membrane. This will also be limited by physical limits of the membrane and the increased cost required to operate at higher pressures.
- Decreasing viscosity and density of the feed material which is generally characterised by turbidity, dry substance, pH, operating temperature and VCF. In many cases, the viscosity and density of the feed material will be set by other factors.
- Increasing diffusivity which is affected by the turbulence and velocity (determined by the recirculating flow rate) through the membrane. The flow channel arrangement will also contribute to the turbulence of the flow.

Permeate flux model

To accommodate the range of conditions investigated and the huge amount of data collected, models were developed to allow flux predictions to be made about expected flux levels for any nominated condition. The statistically significant variables included in the models were temperature, cross-flow velocity of the feed stream (Applexion), pressure drop (KMS), brix of the

feed, and the target VCF. Viscosity was not included in the regression analysis because of the very limited range of values. Separate equations were developed for each membrane type. Average analyses of the clarified juice are:

Brix	18.2 (15.9–21.3)
Turbidity	9 (absorbance at 900 nm)
	26 NTU
pH	7.0

Regression analysis was used on the data to determine model parameters. Forward stepwise multiple regression was applied to obtain a simplified model expression. Only significant regression coefficients were retained in this model. The remaining regression coefficients of the simplified equation were determined with higher precision (according to student t test). This methodology for determining model parameters is similar to that used by Dornier *et al.* (1994) to establish the optimal conditions of cross-flow filtration. The form of the regression equation is as follows:

$$J = \alpha_1 + \alpha_2 \cdot \log(\text{VCF}) + \alpha_3 \cdot T + \alpha_4 \cdot u + \alpha_5 \cdot \text{Bx} \quad (1)$$

where J = Permeate flux, $\text{L}/\text{m}^2 \cdot \text{h}$
 α_x = Coefficients determined by regression
 T = Temperature, $^{\circ}\text{C}$
 u = Velocity, m/s
 Bx = Brix

Predictions from this regression model provided excellent agreement with the raw data with R^2 values greater than 0.96 in all cases. The results showed that the VCF and feed flow velocity were the most important variables affecting flux through the ceramic membranes.

A similar form of the regression equation was developed for the KMS membranes with the pressure drop substituted for the feed velocity and an additional term added to account for the flux decline over time. An example of the quality of fit between the actual data and the model prediction is shown in Figure 5 for one trial with the HYSS membranes.

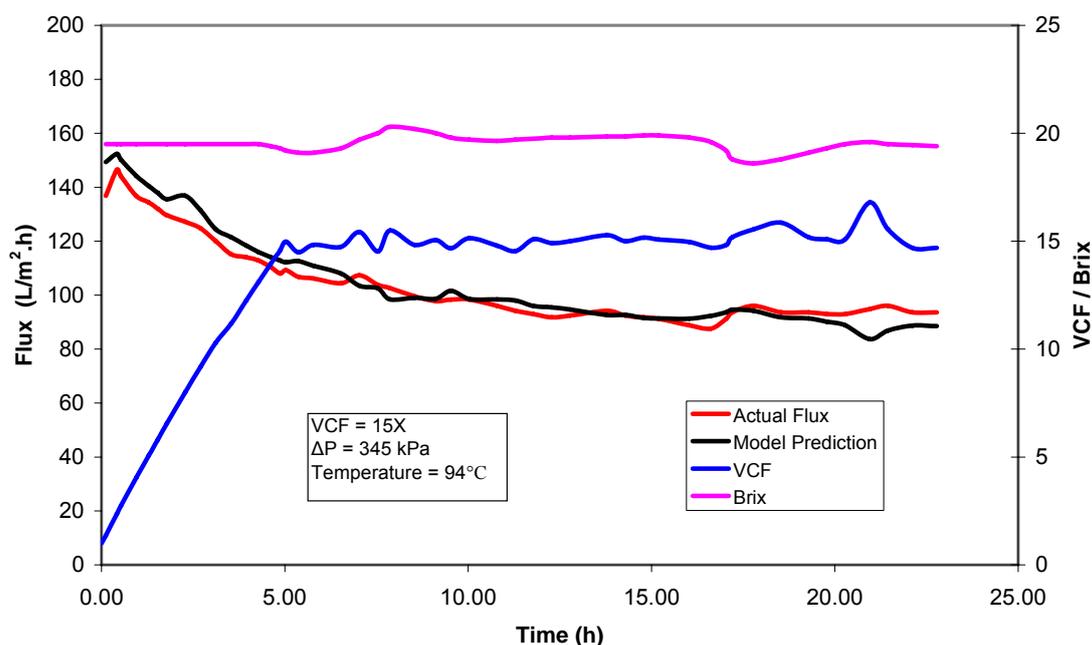


Fig. 5—Example of measured flux and the model prediction of flux for the conditions of the test.

Applexion pilot

The permeate flux predictions for the ceramic membranes are shown in Figure 6. The ceramic membranes, except the KB-W-07 (045), generally gave reproducible results over the two years of trials, were easy to clean and maintain 'clean' flux levels and could handle operation at high VCF (up to 50X). The KB-W-07 (045) membranes experienced fouling and cleaning problems that resulted in a much lower flux being obtained than expected. It was assumed that the larger pore size became blocked more easily and remained blocked during the cleaning cycles.

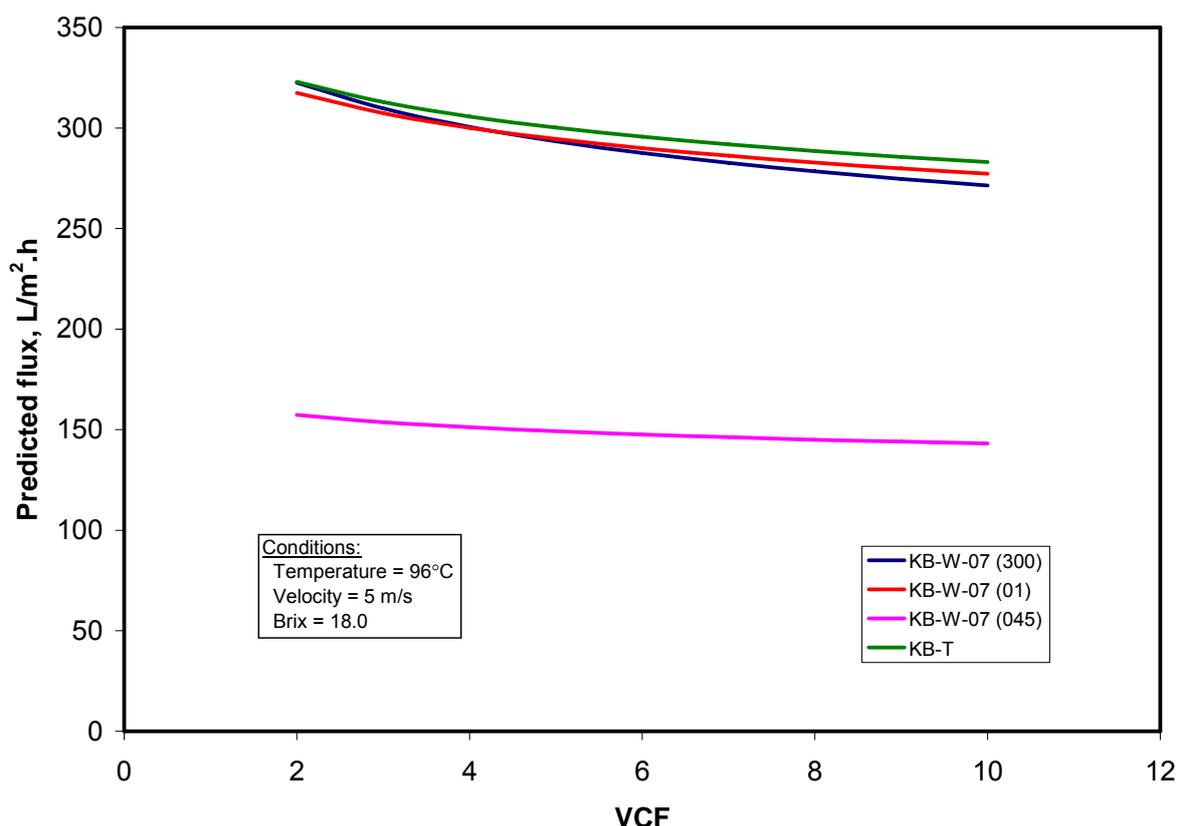


Fig. 6—Predicted flux levels for the different ceramic membranes based on statistical analysis of the raw data.

Interestingly, the flux obtained for the KB-W-07 (300), KB-W-07 (01) and KB-T were very similar. The diameter of the feed channel in the standard KB-W-07 (01 and 300) is 3.5 mm and the nominal diameter of the KB-T channel is 2.6 mm. There was a risk that the tight corners of the oval shaped channels would result in a thicker boundary layer in these regions. However, the measured flux indicated that there was no decline in performance.

The benefit with this profile is that single elements provide 42% extra filter area for the same overall element dimensions. This has implications for the initial plant cost, the replacement cost of membranes and the operating costs.

The spiral organic membranes supplied by Applexion had lower temperature limits and produced much lower fluxes. When compared with the performance of the KMS membranes, the membranes provided by Applexion were not competitive.

KMS pilot

For the KMS membranes, the model can also be used to predict the flux level after a period of operation which is important when determining the required membrane area for a nominated feed rate. Figure 7 illustrates the model predictions for the following typical conditions:

- Temperature: 96°C
- VCF: 10X
- Brix: 18.0 Bx
- Pressure drop (KMS - SS): 485 kPa
- Pressure drop (KMS - HYSS): 415 kPa

The KMS data in Figure 7 show the predicted flux over 22 hours of operation for both the SS and HYSS types.

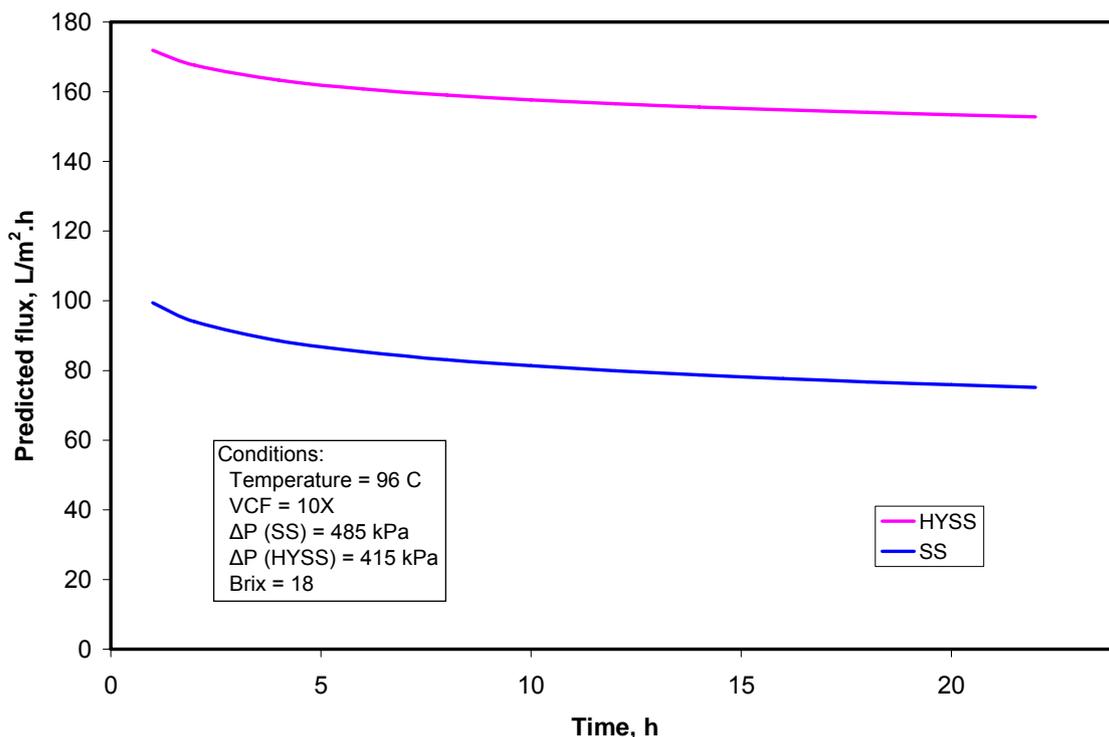


Fig. 7—Predicted flux for spiral organic membranes.

Permeate analyses

The average improvement in juice quality achieved from membrane filtration of clarified juice is shown in Table 2.

The results indicate that there is not a lot of difference in separation performance between the two membrane types. The level of removal appears to be almost independent of the nominal pore size of the various membranes (for the types of impurities of interest) and may be an indication that the dynamic foulant layer on the surface of the membrane influences the efficiency of removal.

Table 2—Summary of juice analyses following membrane filtration.

Pilot	Change (permeate – clarified juice)/clarified juice, %				
	Colour	Turbidity	Total polysaccharides	Starch	Dextran
Applexion	-13	-98	-81	-60	-95
KMS	-13	-99	-87	-60	-97

If the data from all the Applexion plant trials are considered for each MWCO/ pore size range, there is a suggestion from Table 3 that more of the dextran passes through the membrane as the pore size increases. It is not so clear whether starch is similarly affected.

Table 3—Summary of the change in polysaccharide concentration for each size range for all the membranes supplied by Applexion.

Polysaccharide	Initial conc. mg/kg	Change in concentration for each MWCO/pore size, %					
		50 kDa	90 kDa	150 kDa	300 kDa	0.1 µm	0.3 µm
Dextran	237	100	100	100	100	95	70
Starch	214	68	77	78	60	54	63

Pan stage productivity

The laboratory trials in the pilot pan determined that the increase in growth rate averaged 30% (from 221 µm/h to 287 µm/h). For a full pan cycle, the productivity improvement is about 15 to 23%. The improvement is similar to data presented from other investigations (Saska, 1997; Kwok, 1996). The improvement in pan productivity is due primarily to a reduction in viscosity of the syrup of 15 to 20%. This viscosity reduction was expected to flow through to the low grade C massecuite processing and provide an increase in sucrose recovery from final molasses.

The analytical results for the saturated syrup samples that were used to measure crystal growth rates indicate that the solubility coefficient of the feed syrup averaged 0.97 and it did not change following membrane filtration. The lower viscosity and higher growth rates of the syrups also resulted in the production of sugar with lower colour (~40%) reduced ash levels (~35%) and higher filterability (~17%).

Table 4—Summary of the results for the crystal growth rate studies.

Sample source	Viscosity change, %	Growth rate change*, %
Applexion	-16.5	+17.3
KMS	-19.7	+17.6

*Calculated as (membrane filtered data – unfiltered data)/unfiltered data

Cleaning

Several cleaning procedures were assessed for their ability to recover to 'near new' flux levels. Initial CIP trials highlighted the importance of flushing and rinsing the membranes between cleaning cycles and indicated that high quality and hot temperature water improved the overall efficiency of the cleaning process. The detergent cleaning cycle was found to produce the most significant flux recovery.

During the trials, the water flux under standard operating conditions was monitored as an indication of the effectiveness of the CIP cycle and the condition of the membrane modules. After the usual decline in flux when the KMS membranes were first used, the water flux remained relatively constant over the period of the trials even when the membranes were stored for eight months between crushing seasons.

There was insufficient operating time with both the ceramics and the polymerics to determine the likely operating life of either type of membrane.

At the end of the trials, visual assessment and analysis of the water flux data for the KMS spirals were carried out which indicated no physical degradation of the membrane modules or blockages of the recirculating flow path.

Conclusions

A comprehensive assessment of the operation and performance of two membrane plants utilising a range of ultra and micro-filtration membranes was completed. The membrane types included spiral wound and tubular ceramic membranes covering a wide range of pore or MWCO sizes.

The 0.1 μm and the 300 kDa ceramic membrane elements provided the highest flux of the membranes tested. The factors that have a major influence on the flux rating are the feed properties including temperature, brix, and concentration of the impurities together with the feed velocity and pressure. The feed channel diameter and profile of the ceramic membranes only had a small influence on the achievable filtration rates. On the other hand, the width and the design of the spacer used to provide the feed channel in the KMS spiral membranes has a significant effect on the filtration rate.

Despite the larger pore sizes of the ceramic membranes, the separation efficiencies were similar to those achieved with the much tighter spiral membranes from KMS. It was assumed that the dynamic foulant layer played a major role in separating high molecular weight impurities from the juice stream.

The studies have shown that the ability to separate impurities from the juice was similar for both the ceramic and spiral membranes. The average reduction in impurity concentration is summarised as follows: colour 13%, turbidity 99%, polysaccharides 83%, starch 56%, and dextran 90%. As well, the membrane filtration of clarified juice led to improvements in downstream processes including an increase in crystal growth rate of 15 to 23% resulting from the reduction in viscosity of the syrup by 15 to 20%. The lower viscosity and higher growth rates of the syrups also result in the production of sugar of lower colour (~40%), reduced ash levels (~35%) and higher filterability (~17%).

A range of operating conditions was applied to each pilot. These data were then used to develop prediction models for each type of membrane. The fit to the experimental data was excellent. The models provide a useful tool to determine flux levels through each of the membrane types for a wide range of possible operating conditions.

Acknowledgements

The funding provided by the Sugar Research and Development Corporation and a syndicate of Australian sugar mills is acknowledged. The assistance provided by both Applexion and Koch Membrane Systems was extremely important to the success of the project.

REFERENCES

- Broadfoot, R. and Steindl, R.J.** (1980). Solubility-crystallisation characteristics of Queensland molasses. *Proc. Int. Soc. Sugar Cane Technol.*, 17: 2557–2581.
- Cheryan, M.** (1986). *Ultrafiltration handbook*. Technomic Publishing Company, Inc., Pennsylvania.
- Dornier, M., Decloux, M., Lebert, A. and Trystram, G.** (1994). Use of experimental design to establish optimal crossflow filtration conditions: Application to raw cane sugar clarification. *J. Food Proc. Eng.*, 17: 73–92.
- Jensen, C.R.C., Kitching, S.M., Rosettenstein, S. and Ahmed, F.** (2006). The application of WSM technology at Felixton Mill, South Africa. *Proc. Process Workshop, Int. Soc. Sugar Cane Technol.*, Louisiana, U.S.A.
- Kwok, R.J.** (1996). Ultrafiltration/softening of clarified juice—The door to direct refining and molasses desugarisation in the cane sugar industry. *Proc. S. Afr. Sug. Technol. Ass.*, 70: 166–170.
- Kwok, R.J., Lancrenon, X. and Theoleyre, M.A.** (1996). Process manufacturing crystal sugar from aqueous sugar juice such as cane juice or sugar beet juice, U.S. Patent No. 5, 554,227.
- Madsen, R.F.** (1973). Application of ultrafiltration and reverse osmosis to cane juice. *Int. Sugar. J.*, 75: 163–167.
- Saska, M.** (1997). *Sugarcane Research: Annual Progress Reports*, Audubon Sugar Institute, Louisiana State University.
- Steindl, R.J.** (2001). Membrane filtration technology in the cane sugar industry. *Proc. Int. Soc. Sugar Cane Technol.*, 24: 3–14.

FILTRATION MEMBRANAIRE DE JUS DE CLARIFICATION

Par

R.J. STEINDL et D.W. RACKEMANN

Sugar Research and Innovation, Queensland University of Technology, Australie
r.steindl@qut.edu.au**MOTS-CLEFS: Filtration sur Membrane,
Céramiques, Polymères, Flux, Encrassement.****Résumé**

UNE UNITE de filtration sur membrane à l'aide de membranes micro- ou ultra-filtration a le potentiel d'augmenter la capacité des cuites et d'améliorer la qualité du sucre. Des travaux précédentes par le SRI et d'autres ont montrés que les membranes enlèvent les polysaccharides, la turbidité et les impuretés colloïdales, et donnent des sirops et mélasses avec des viscosités plus faibles. Cependant, la conclusion de ces enquêtes a été que la filtration membranaire n'était pas économiquement viable. Une évaluation complète de la technologie des membranes de la génération actuelle a été entreprise par SRI. À l'aide de deux systèmes pilotes provenant de Membrane Koch et d'Applexion, des essais ont été effectués dans une usine australienne avec du jus clarifié à 80–98 ° C alimentant chaque unité. Les conditions ont été variées durant les essais afin d'examiner l'effet d'une gamme de paramètres d'exploitation sur les caractéristiques de filtrage de chacune des membranes. Ces paramètres sont la température et pression de l'alimentation, la vitesse du jus, les solides solubles et la concentration des impuretés. Les données ont été ensuite combinées dans des modèles afin de prédire le taux de filtration (ou flux) pour les conditions d'exploitation désignées. Les modèles donnent un très bon accord avec les données recueillies durant les essais. Les essais ont également identifiés les membranes qui fournissent les plus hauts niveaux de flux par unité de surface de membrane pour des conditions spécifiques. Des procédures de nettoyage ont été mises au point et le flux d'eau a été retrouvé après un processus de nettoyage en place. Des échantillons de jus de clarification et de jus filtré par les membranes de chaque pilote ont été évaporés pour produire du sirop, afin de quantifier le gain de productivité qui résulte aux cuites grâce à l'élimination des impuretés de haut poids moléculaire par filtration sur membrane. Les résultats sont en accord avec ceux publiés par d'autres groupes de recherche.

FILTRACION CON MEMBRANAS DE JUGO CLARIFICADO

Por

R.J. STEINDL and D.W. RACKEMANN

Sugar Research and Innovation, Queensland University of Technology, Australia

r.steindl@qut.edu.au

PALABRAS CLAVES: Filtración con Membranas, Membranas Cerámicas, Membranas Poliméricas, Flux, Incrustaciones.

Resumen

EL USO de micro o ultrafiltración con membranas tiene el potencial de incrementar significativamente la capacidad de los tachos y mejorar la calidad del azúcar. Investigaciones anteriores realizadas por el SRI y otros investigadores han mostrado que las membranas remueven polisacáridos, turbiedad e impurezas coloidales, disminuyendo la viscosidad de las meladuras y mieles. Sin embargo, estos estudios han concluido que el uso de membranas no es una alternativa económicamente viable. Una valoración comprensiva de la tecnología actual en membranas fue realizada por el SRI usando dos plantas piloto suministradas por Applexion y Koch Membrane Systems. Se realizaron una serie de ensayos en un ingenio australiano, alimentando a cada planta piloto jugo clarificado a una temperatura entre 80 y 98°C. Durante los ensayos se variaron algunas condiciones para evaluar efecto de variaciones en los parámetros de operación sobre las características filtrantes de cada una de las membranas. Estos parámetros incluyeron la temperatura y presión del alimento, la velocidad del flujo, y la concentración de sólidos solubles e insolubles. Los resultados obtenidos fueron usados en un modelo para predecir la velocidad de filtración que podría ser esperada para unas condiciones de operación determinadas. Los modelos mostraron una muy buena correlación con los datos recolectados en los ensayos. Se identificaron para unas condiciones de operación determinadas aquellas membranas que presentaron el mayor nivel de flujo por unidad de área de membrana (flux). Se desarrolló un proceso de limpieza para asegurar que el agua utilizada en la limpieza de la membrana fuera recuperada en el mismo lugar de su uso. Se concentraron hasta meladura muestras de jugo clarificado filtrado y sin filtrar de cada una de las dos plantas piloto para cuantificar la ganancia en la productividad en la etapa de tachos como resultado de la remoción de impurezas de alto peso molecular durante la filtración con membranas. Los resultados obtenidos coinciden en general con aquellos obtenidos por otros grupos de investigación.