CHEMICAL ENGINEERING TRANSACTIONS Volume 25, 2011
Editors Jiří Jaromír Klemeš, Petar Sabev Varbanov, Hon Loong Lam
Copyright © 2011, AIDIC Servizi S.r.l., ISBN 978-88-95608-16-7 ISSN 1974-9791
DOI: 10.3303/CET1125181

Energy Savings in Sugar Manufacturing with the Implementation of a new Membrane Process

Saeed Gul, Michael Harasek*

Vienna University of Technology, Institute of Chemical Engineering, Austria
Getreidemarkt 9/166, A-1060 Vienna, michael.harasek@tuwien.ac.at

In sugar manufacturing the thin juice is concentrated from initial feed concentration of 15 w% to 65-70 w% through evaporation. Membrane technology can be applied to contribute in this as pre-concentration step. In the present work energy saving has been calculated for the concentration of thin sugar juice with the implementation of a newly developed multistage pressure driven membrane process that concentrate thin sugar juice from initial feed concentration of 15 w% to the 50 w%. The process is capable to remove 70 w% of the water from the thin juice without any application of heat and phase change. The final concentration is to be done in multiple effect evaporation to reach 65-70 w%. The calculation has shown that the combined multistage membrane process and evaporation not only reduces energy consumption of evaporation by 86.9 % (for increasing the concentration from 15 w% to 65 w%) but also reduces the role of multiple effect evaporation in the sugar manufacturing.

1. Introduction

The optimum temperature for the extraction of sucrose from sugar beet in the beet sugar industry is about 70-73 °C. The juice is then heated to 80-90 °C in purification section for liming and carbonation processes to remove non-sugars. After purification the juice is called thin juice and is at about 80 °C with 15 w% sucrose. This thin juice is then concentrated in multiple effect evaporators up to 65-70 w%. Evaporation is one of the most energy intensive unit operations in sugar factories. It has two main drawbacks. Firstly, it consumes a huge amount of energy due to high latent heat of water and secondly, heating may decompose the sugar molecules resulting in low quality and dark coloured sugar (Madaeni at al. 2004). As membrane technology has the capability to remove water from the aqueous solutions without phase change therefore it consumes less energy compared to any other separation process. Reverse osmosis and/or nanofiltration can be used to pre-concentrate thin juice to decrease the thermal load on evaporators and save energy. In the previous studies thin juice was pre-concentrated from the initial feed concentration of 15 w% to 20-25 w% (Gul and Harasek, 2009; Madaeni and Zereshki, 2008). As the osmotic pressure and viscosity of the aqueous sucrose solution increases exponentially with concentration therefore high osmotic pressure was the barrier in these studies for the maximum economical concentration up to 20-25 w%. Secondly in the previous studies thin juice was cooled to 25-40°C to pass through membranes as the maximum operating temperature limit was the barrier. Sugar juice at low temperature is favourable for microbial growth which converts the sugar

Please cite this article as: Gul S. and Harasek M., 2011, Energy savings in sugar manufacturing with the implementation of new membrane process, Chemical Engineering Transactions, 25, 1085-1090
DOI: 10.3303/CET1125181

into lactic acid and inverted sugar (Asadi, 2007). Also cooling the juice and heating it again after membrane process needs heat exchangers and requires energy. In the present study a newly developed multistage pressure driven membrane separation processes has been applied to concentrate the thin sugar juice from initial feed concentration of 15 w% to 50 w% with moderate transmembrane pressure of 32 bar and 80 °C. The process is capable to remove 70 w% of water from the solution without any phase change. The preconcentrated solution can then be sent to evaporator for final concentration up to 65-70 w%. The hybrid concentration process of membrane and evaporation can save more than 85 % of energy and is an environmentally friendly process.

2. Experimental

A bench-scale crossflow membrane unit OS-MC-01 from Osmota with effective membrane area of 0.008m² was used to concentrate model sugar solution from 15 w% to 50 w%. Sugar concentration was measured by a digital refractometer. The experiments were done at constant pressure and temperature mode. The permeate weight was measured with electric balance in specified intervals and the flux was calculated from it. Pure water permeability was tested before and after each experiment.

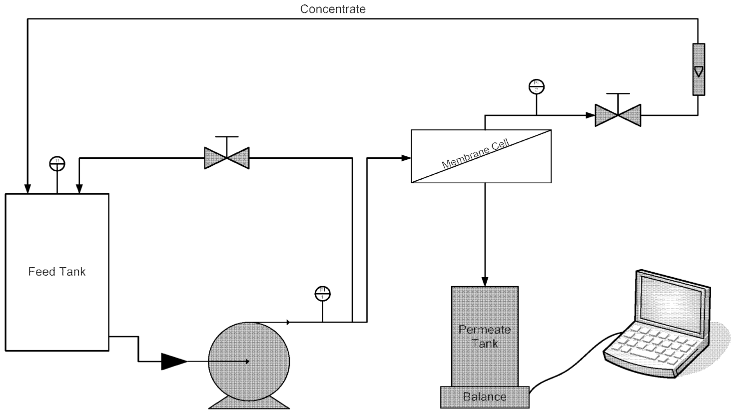

Figure 1: Experimental setup

3. New multistage pressure driven membrane concentration process

Pressure driven membrane processes like reverse osmosis is not generally able to go as high a concentration as evaporation. Osmotic pressure, viscosity and solubility set the upper limit of the concentration through reverse osmosis (Pepper, 1990). Classical reverse osmosis concentration processes is economically limited to concentration between 25 and 30 w% as a pre-concentration step. The new multistage pressure driven membrane concentration processes is capable to concentrate sugar solution up to 45 to 50 w% at moderate operating pressure of 32 bar which is well below the osmotic pressure of 102 bar of the concentrated product solution. Higher concentration at moderate applied pressure has the advantage of low capital and operating cost.

4. Energy consumption

4.1 Energy consumption of reverse osmosis

Reverse osmosis uses pressure to concentrate a solution by forcing water through a semi permeable membrane which allows the water to pass through but prevent the passage of solutes. The pressure produced by the high pressure pump must overcome the osmotic pressure of the solution at the membrane surface.

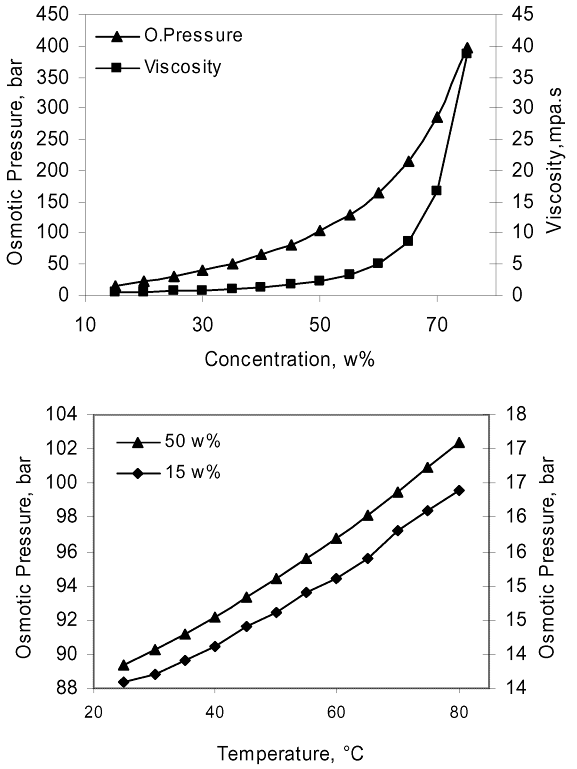

Figure 2: A) Effect of sucrose concentration on osmotic pressure and dynamic viscosity B) Effect of temperature on osmotic pressure of aqueous sucrose solution

The osmotic pressure is the function of the concentration and temperature. Figure 2 illustrates the effect of concentration and temperature on osmotic pressure and dynamic viscosity. For aqueous sucrose solution the osmotic pressure increases exponentially with concentration. The viscosity of the sucrose solution also increases with concentration and the increase is very rapid after 50 w%. The increase in viscosity from 15 w% concentration to 50 w% is less than 5 times while from 50 w% to 75 w% the viscosity increases by more than 16 times. The osmotic pressure also increases with temperature. The osmotic pressure of sucrose solution increases from 13.6 bar to 16.4 bar for 15 w% and 89.4 bar to 100.2 bar for 50 w% solution from 25 °C to 80 °C. Therefore, the concentration beyond 50 w% through membrane will not be economical and or feasible mainly because of very high viscosity.

High pressure pump is the main energy consuming component of the reverse osmosis processes to remove water from the solution. The theoretical amount of energy required to separate water from a solution by reverse osmosis is the volume moved times the pressure used to move it:

$$E_p = \frac{q_v \Delta P}{\eta} \tag{1}$$

Where E_p is the power (W), q_v is the flow rate (m^3/s), ΔP is the pressure difference (N/m^2) and η is efficiency. The efficiency of the high pressure piston pump is generally between 0.5 and 0.8.

4.2 Energy consumption of multiple effect evaporator

The amount of water to be removed by evaporation in a beet sugar factory is about 95 %. Typically, 75 % of beet is water and about 20 % water is added during the production processes. Evaporating this 95 % water consumes enormous amounts of energy due to high latent heat of water. Theoritically single effect evaporation uses 1 kg of steam to evaporate 1 kg of water. In multiple effect evaporation, 1 kg steam entering the first effect can evaporate as many kilogram of water as there are effects in the evaporation [Asadi, 2007]. In multiple effect-evaporators the vapor produced in the first effect is used as a heating medium in the second effect and so on. The amount of water to be evaporated in the evaporation can be calculated as:

$$W_{evp} = F_o(1 - x_f / x_p) \tag{2}$$

Where W_{evp} is the flow rate of water to be evaporated, F_o is the feed flow rate to the evaporator, x_f and x_p are the feed and product concentrations respectively. In the absence of vapor bleed the amount of steam needed in multiple effect evaporation can be calculated by dividing the total amount of water to be evaporated by the total number of effects. For example for 100 kg water to be evaporated in 5-effect evaporator, 20 kg of steam will be required to feed in the first effect. The minimum energy required for evaporation can be calculated through equation:

$$E_{th} = m_s \lambda \tag{3}$$

Where E_{th} is the thermal power (kW), ms is the mass flow rate of the steam (kg/s) and λ is the latent heat of water evaporation (kJ/kg).

5. Energy consumption comparison of membrane and evaporation

A joule of energy in the form of heat and a joule of energy in the form of electricity are not equally valuable. Typically the thermal electric power plants have energy conversion efficiencies around 40 % and therefore electricity that comes out of a power plant is clearly more valuable than the thermal energy that goes in (Coventry and Lovegrove, 2003). Since the main energy consuming component of the pressure driven membrane is the high pressure pump which uses electrical energy while evaporation use thermal energy for evaporating water from solutions. The net advantage may be estimated using the method of the substitution coefficient introduced by Electricite de France (Molinari et al, 1995). This coefficient compares the primary energy saved to the electrical energy consumed in cycles that utilise electricity-consuming operations in substitution of conventional thermal operations. The substitution coefficient is defined by the ratio of the primary energy (thermal) saved in the new process with respect to the conventional processes and the amount of electrical energy consumed, relative to the conventional processes:

$$CS = \frac{C_1 - C_2}{E_2 - E_1} \tag{4}$$

Where CS is the substitution coefficient, C the consumption of thermal primary energy (MJ or Mcal), E the consumption of electrical energy (kWh), 1 and 2 the relative index of the conventional and innovating process, respectively. Taking into account that 1 kWh of electrical energy requires a power plant to burn about 10.5 MJ of primary energy from a combustible source (oil, gas, coal etc.), the substitution is acceptable when the CS value is greater than 10.5 MJ/kWh (2.5 Mcal/kWh).

In the present work multistage pressure driven membrane processes has been used in combination with 5-effect evaporator for the concentration of clarified thin sugar juice. Calculation has shown 86.9 % reductions in the energy consumption of the concentration process from 15 w% to 65 w% and a primary energy saving of 72.24 MJ/kWh.

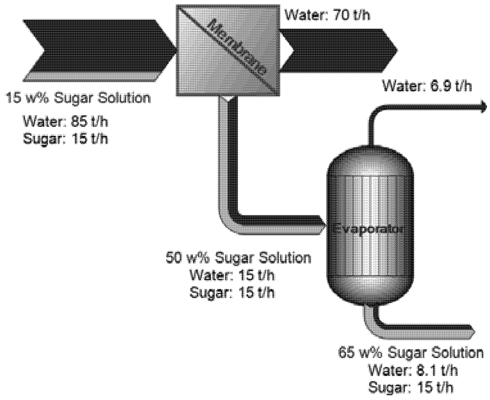

Figure 3: Proposed process for thin juice concentration from 15 w% to 50 w% with membrane and from 50 w% to 65 w% through evaporation.

Table 1: Energy consumption comparison and saving for 100 t/h feed of thin sugar juice for 5-effect evaporator and pressure driven membrane from 15 w% to 65 w%.

Process	Energy consumption kWh	Energy Saving %	Primary Energy Saving, MJ/kWh
Evaporator	11680	**86.9**	**72.24**
Membrane + Evaporator	503 + 1033		

6. Discussion and conclusion

In this work a new multistage pressure driven membrane technology has been applied for preconcentration of thin sugar juice from initial feed concentration of 15 w% to 50 w% at moderate pressure of 32 bar and 80°C. In a classical single stage pressure driven membrane processes for thin sugar juice concentration of 50 w%, a transmembrane pressure of more than 102 bar is necessary. This very high transmembrane pressure is not only uneconomical but at 80°C is not even possible to find operating conditions for the presently available polymeric membranes. The new process is capable to remove 70 w% water from the thin sugar juice and save 86.9 % energy. The process has reduced the role of multiple effect evaporation which is a thermal process that reduces the chances of thermal degradation of the juice. The application of the new process in the existing sugar industry will increase the capacity of the present evaporation stage.

References

Asadi M., 2007, Beet-Sugar Handbook, John Wiley & Sons, Inc, New Jersey, USA.

Coventry J. S. and Lovergrove K., 2003, Development of an approach to compare the value of electrical and thermal output from a domestic PV/thermal system, Solar Energy, 75, 63-72.

Gul S. and Harasek M., 2009, Combined membrane-evaporation process (C-map) for thin sugar juice concentration, IMeTI workshop on “Membrane applications in agrofood”, October 18-20, Cetraro (CS), Italy.

Madaeni S.S, Tahmasebi K., and Kerendi S. H., 2004, Sugar syrup concentration using reverse osmosis membranes, Eng. Life Sci, 4, 187-190.

Madaeni S.S. and Zereshki S., 2008, Reverse osmosis alternative: Energy implication for sugar industry, Chem. Eng. Process, 47, 1075-1080.

Molinari R., Gagliardi R. and Drioli E., 1995, Methodology for estimating saving of primary energy with membrane operations in industrial processes, Desalination, 100, 125-137.

Pepper D., 1990, Concentration in the food and beverage industries without evaporation, The Membrane Alternative: Energy Implications for Industry, Watt Committee Report Number 21, Elsevier Applied Science, London and New York.