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Comparative study of red grape must nanofiltration: Laboratory and pilot plant scales

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ABSTRACT

A consequence of global warming is the early ripening of grapes which promotes, among others, a higher fermentable sugar (glucose and fructose) content. This leads to wines with an alcoholic degree higher than desired.

In this work, the main differences between red grape must nanofiltration at laboratory and pilot plant scale were studied in order to perform the scale-up of a nanofiltration process to reduce the sugar content. For this, previous results of the nanofiltration of commercial red must using the SR3 membrane in a flat sheet crossflow module were compared with those obtained for the filtration of natural red must using the same membrane in a spiral wound module at two different applied pressures.

The aim of this publication is to analyze the main differences between red grape must nanofiltration at laboratory and at pilot plant scale.

Results: showed that the flow destabilization and eddy promotion caused by spacers in the spiral wound module mitigate the rate at which the cake thickens and compacts on the membrane surface. This causes a less sharp flux decrease, less variable sugars rejection and osmotic pressure difference. Moreover, higher applied pressure promotes a higher membrane fouling and osmotic pressure that worsen the flux decay.

Keywords: Red grape must; Nanofiltration; Scale-up; Spiral wound module; Sugar content reduction

1. Introduction

Membrane processes are now widely considered as economical alternatives to conventional separation processes. Reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) have become standard unit operations (Schwinge et al., 2004).

Membranes can be presented in several configurations such as: spiral wound, hollow fibers, tubular and plate-and-frame modules. Amongst these, the hollow fiber and the spiral wound modules are the most commonly used, due to their high membrane area to volume ratio. Moreover, spiral wound modules are often preferred in industry because they offer a good balance between ease of operation, fouling control, permeation rate and packing density (Geraldes et al., 2002; Schwinge et al., 2004).

Some membrane processes have been used in winemaking for a long time. For example: cross-flow MF and UF to clarify white grape must (Cassano et al., 2008), sugar concentration using NF (Versari et al., 2003) and RO (Rektor, 2007) in musts. Reverse osmosis is also used to reduce alcohol in wines, unfortunately, RO membranes are permeable to both alcohol and water, and after the filtration it is necessary to add water to the dealcoholized wine which creates legal problems in some countries where the addition of water is forbidden by law (García-Martín et al., 2010).

Furthermore, more recent research and development activities have focused on the application of membrane

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Nomenclature

Roman

A_{eff}	effective area (m^2)
A_m	membrane active area (m^2)
a_{sp}	specific surface area of the spacer
A_{sp}	surface area of the spacer (m^2)
$C_{0,i}$	feed concentration of the ith component (kg/m^3)
$C_{m,i}$	concentration of the ith component on the membrane active layer (kg/m^3)
$C_{p,i}$	permeate concentration of the ith component (kg/m^3)
C_{RT}	total sugar concentration (glucose and fructose) of the retentate (kg/m^3)
d	dilament thickness (m)
d_h	hydraulic diameter of the channel (m)
D_i	diffusion coefficient of the ith component (m^2/s)
H	feed channel height (m)
Jv	permeate flux per unit of area through the membrane (m^3/m^2 s)
Jv_0	permeate flux per unit of area through the membrane at time t = 0 (m^3/m^2 s)
k	general kinetic constant for the fouling models (s^{-1})
k_c	kinetic constant for the cake model (s/m^6)
$K_{m,i}$	mass transfer coefficient (m/s) of the ith component at impermeable membranes (m/s)
$K^s_{m,i}$	mass transfer coefficient of the ith component at semipermeable membranes (m/s)
L	leaf length (m)
l_m	mesh size (m)
L_p	water permeability (m/Pa s)
M_i	molar weight of the ith component (kg/mol)
n	dimensionless exponent which depends of the fouling model
Q	volumetric recirculation flow (m^3/s)
R	ideal gas constant (1.987×10^{-3} kcal/mol K)
Re	Reynolds number
R_f	resistance due to fouling (m^{-1})
R_i	membranes true retention for the ith component
R_m	membrane resistance (m^{-1})
R_{Sys}	system resistance (m^{-1})
Sc	Schmidt number
Sh	Sherwood number
T	absolute temperature (K)
V_0	initial volume of grape must (m^3)
V_P	permeate volume (m^3)
V_{sp}	volume occupied by the spacer (m^3)
V_t	volume of the total (empty) channel (m^3)
W	leaf width (m)

Greek

β	angle between crossing filaments
Δp	applied transmembrane pressure (Pa)
Δp_c	pressure drop across the cake (Pa)
Δp_m	pressure drop across the membrane (Pa)
$\Delta\pi$	osmotic pressure gradient (Pa)
ε	feed spacer porosity
η	viscosity of the solution that passes through the membrane (Pa s)
η_f	feed viscosity (Pa s)
η_p	viscosity inside the membrane pore (Pa s)
θ	angle of the feed flow
ϑ_{eff}	effective velocity (m/s)
ρ_f	feed density (kg/m)

technologies for sugar control in grape musts in order to reduce the alcohol content of the resulting wines (García-Martín et al., 2009, 2010, 2011). As a consequence of global warming, an early ripening of grapes has been detected in some regions that causes higher fermentable sugar (glucose and fructose) content, lower acidities and some modifications of the varietal aroma compounds. Fermentation of this must leads to alcoholic degrees higher than desired (Mira de Orduña, 2010), as they may be too burning in the mouth and mask the fruity aromas and taste of wine. Premature grape harvest and winemaking should affect the final wine quality, leading to more acid and less colored wines, because the phenolic maturity would not be fully achieved (García-Martín et al., 2011). Therefore, in order to produce a full flavored wine, the harvest should be carried out in the optimum ripeness of the fruits and then innovative techniques to control sugars in musts should be applied to keep the alcohol degree of the resulting wines within the desired range. Moreover moderated alcohol contents are becoming a trend in the consumers demand.

If the molecular weight of sugars in must is taken into account, nanofiltration seems to be the most appropriate technique to control the concentration of glucose and fructose (García-Martín et al., 2009). In their work, García-Martín et al. (2010, 2011) studied the sugar reduction of fermentable sugars in musts such as glucose and fructose by a 2 stage nanofiltration process to obtain wines with a slight alcohol reduction. Their results showed that the mixture of the final permeate with the retentate or with untreated must in adequate proportions reduced the alcohol content of the resulting wines by 2°. However, a slight loss of color and aroma intensity and a slender unbalancing of some important substances (i.e. potassium, malic and tartaric acid) were detected. Moreover, these experiments of must nanofiltration, showed that there are some problems specially related with the permeate flux decline.

In our previous work (Salgado et al., 2013), a method was proposed to study the influence of the different compounds present in red grape must on flux decline. Results showed that high molecular weight compounds (namely polyphenols, polysaccharides, proteins, etc) have more influence on the permeate flux decay since they are mainly responsible for the fouling phenomenon (cake filtration mechanism). While low molecular weight compounds (mainly glucose and fructose), contribute to the flux decay mostly through an increase of the osmotic pressure during the process. Aiming to select the most appropriate NF membrane for sugar control in grape must, further research was performed applying the same methodology mentioned in previous works (Salgado et al., 2013). In this work (Salgado et al., 2012), the performance for must nanofiltration of 3 flat sheet NF membranes was compared: the NF270 (Dow Filmtec), HL (GE) and SR3 (Koch Membrane System). The results obtained showed that the HL and SR3 membranes were appropriate to reduce the content of sugar of red must. Specifically, the SR3 membrane showed the best passage of sugar and less fouling. Once the membrane is selected at a laboratory