Note

Water production from food processing wastewaters using integrated membrane systems: A sustainable approach

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Abstract

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This scientific note reviews current approaches for using membrane technology to treat wastewater from food processing, for example, as a means to produce water by recovering components with high added value. In addition, with regard to the availability of wastewater, processes that contain membranes have been shown to be advantageous in terms of treating waste, recovering solutes, and producing water. With regard to the latter, processes that contain membranes can be considered to be a sustainable methodology given the valorization of waste. Lastly, this note provides a brief general view emphasizing a real need to apply membrane technology in the food industry, and indicates that its application is undoubtedly to come.

Keywords: Wastes, microfiltration-ultrafiltration, nanofiltration, treatment, sustainability, recovery.

Resumen

Castro-Muñoz, R., Fíla, V., Rodríguez-Romero, V. M., & Yáñez-Fernández, J. (noviembre-diciembre, 2017). Producción de agua a partir de aguas residuales del procesamiento de alimentos mediante sistemas integrados de membrana: enfoque sustentable. Tecnología y Ciencias del Agua, *8(6), 129-136, DOI: 10.24850/j-tyca-2017-06-09.*

Esta nota científica revisa los enfoques actuales de la tecnología de membranas para el tratamiento de residuos del procesamiento de alimentos; por ejemplo, como vía para la producción de agua a través de la recuperación de componentes de alto valor agregado. Además, se ha demostrado que los procesos integrados de membrana pueden ofrecer la ventaja de realizar las siguientes tareas en términos de disposición de aguas residuales: tratamiento de residuos, recuperación de solutos y producción de agua. Esto último permite considerar a los procesos integrados de membrana como una metodología sustentable a través de la valorización de residuos. Por último, esta nota provee una breve visión general, resaltando que la aplicación de la tecnología de membranas en verdad es necesaria en la industria alimentaria y que seguramente su implementación real aún está por venir.

***Palabras clave**: residuos, microfiltración-ultrafiltración, nanofiltración, tratamiento, sustentabilidad, recuperación.*

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Introduction: Food processing wastewaters

As it is well known, the waste disposal from agro-food industries is a current issue regarding environmental aspects. One of the most produced wastes in the food industry is the wastewater (WW), which is commonly derivatives from typical processing steps such as cooking, pre-cooking, treatment, washing and peeling. These WW present high organic contents associated to their high content of lixiviated compounds. Different types of methodologies have been applied to WW to decrease the chemical oxygen demand (COD) in the extracts. Methods, such as ozonation (Ternes *et al*., 2003), catalysis by using anaerobic reactor (Green *et al*., 2006), electrochemical treatment (Rajkumar & Palanivelu, 2004), coagulation, adsorption (Abdessemed, Nezzal, & Ben-Aim, 2000) and coupled methods (Lin & Peng, 1996), have been evaluated during last decades. Also, the recovery of specific components has been tested by solvent extraction (Okuda, Yamashita, Tanaka, Matsukawa, & Tanabe, 2009); however, these procedures are not potentially applied due to large quantities of supplies needed. Recently, pressure-driven membrane processes have been proposed for the treatment of food wastewaters (Van der Bruggen, Vandecasteele, Van Gestel, Doyen, & Leysen, 2003a; Van der Bruggen, Lejon, &Vandecasteele, 2003b). Specifically, micro (MF), ultra (UF) and nano (NF)- filtration processes were applied in Europe for the treatment of different wastewaters such as olive mill wastewater (OMWW) (Paraskeva, Papadakis, Tsarouchi, Kanellopoulou, & Koutsoukos, 2007; Russo, 2007; Galanakis, Tornberg, & Gekas, 2010; El-Abbassi, Khayet, & Hafidi, 2011; Cassano, Conidi, & Drioli, 2011), artichoke wastewater (AWW) (Conidi, Cassano, & Garcia-Castello, 2014), orange press liquor (OPL) (Conidi, Cassano, & Drioli, 2012) and winery sludge (Galanakis, Markouli, & Gekas, 2013). The last approaches were developed with the full purpose of recovering several valuable compounds; furthermore, these membrane operations offer different advantages in comparison with other methodologies widely tested (decantation separation, dissolved air flotation, de-emulsification, coagulation and flocculation) (Cheryan & Rajagopalan, 1998; Castro-Muñoz, Yáñez-Fernández, & Fíla, 2016a), such as: i) high productivities in terms of permeate fluxes, ii) absence of phase transition, iii) lack of additional phase, iv) easy operating conditions and v) high selectivity towards macro and micro-solutes (Conidi *et al*., 2014). However, some disadvantages can also be identified, e.g., the high cost of these pressure-driven processes is represented by the membrane, as well as the energy requirement that provides the driving force (Galanakis, Castro-Muñoz, Cassano, & Conidi, 2016), whereas their performances are limited by several factors such as concentration polarization, cake layer growth and fouling (Bubolz, Wille, Langer, & Werner, 2002). Indeed, these membrane processes are part of the "Universal Recovery Process" conformed by five stages according to Galanakis (2015): a) macroscopic pre-treatment, b) separation of macro and micro-molecules, c) extraction, d) isolation-purification, and e) product formation. Where MF, UF and NF can be used from the first to fourth stage. Currently, the most explored application of the membrane operations is focusing on the recovery of high-added value compounds from agro-food by-products. The main compounds that have been found in food processing WW are: polyphenols, carbohydrates (sugars), anthocyanins, proteins, pectin's and some other high-added-value compounds (Castro-Muñoz, Orozco-Álvarez, & Yáñez-Fernández, 2015a; Galanakis, 2015). In some cases, the final permeate coming from the membrane operations presents low organic load. These permeates seem to be streams which can be suitable for reuse as process water. This short communication provides a clear overview of the recent experimental cases about the membrane processes that were able to produce water streams as final samples.

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Integrated membrane system developments on water production

The recovery of valuable components is an amazing and current challenge for the research and development (R & D). Like it previously stated, the membrane processes are considered as established and useful technologies for doing this recovery task (Galanakis, 2012). The innovation of these approaches is according to the design of the membrane processes. Different research groups have proposed the integrated membrane systems as via for the fractionation of several WW, as well as recovering the valuable compounds. The Integrated Membrane Process (IMP) is the use of more than one membrane operation in a sequential design; this approach leads to obtain different streams from a feeding stream. Indeed, the permeate obtained from a previous step is the feeding stream of a new membrane operation. For instance, Cassano, Conidi, Giorno and Drioli (2013) started to use IMPs for the fractionation of OMWWs, where the suspended solids and phenolic compounds were recovered. Otherwise, the final permeate obtained from the last membrane operation (NF) was also relevant due to a clear permeate with low Total Organic Carbon (TOC) concentration was produced (95 mg L^{-1}); table 1 shows the water stream obtained and the characteristics of the used IMP. Also, the authors suggested the reuse of this water stream as water process in the following oil extraction processes or the membrane cleaning procedure used for the treatment of this WW. The use of this clear permeate can be used as water for diafiltration to increase the phenolic content in the extract; if the concentration of this valuable compound is needed. The study provides three potential uses for the water stream recovered by a common effluent. Also, a clear permeate was also obtained from the concentration of flavanones and anthocyanins during the treatment of orange press liquor (OPL) through using an IMP, the final permeate presented low content in total soluble solids, which were identified as minerals and sugars. However, the permeate sample was not reported (Cassano, Conidi, & Ruby-Figueroa, 2014).

On the other hand, AWWs have also been evaluated as new source of recovering high-added value compounds (sugars and phenolics). Conidi *et al.* (2014) performed successfully the recovery step by using an IMP. The final water also presented enough characteristics to use the stream as process water or for membrane cleaning. According to the water characteristics reported in table 1, the reuse of this water is potentially suggested due to the minimal content of low molecular weight components that could not be identified by sensitive methodologies, like HPLC. Moreover, the same research group proposed another integrated membrane system to recover specific sugars (fructose, glucose, and sucrose) and polyphenols (apigenin, cynarin and chlorogenic acid) in two different streams from AWWs (Cassano, Conidi, Ruby-Figuera, & Castro-Muñoz, 2015). Likewise, a clear permeate free of sugars and phenolic compounds from the second NF step was obtained; the authors suggested the reuse of this stream for irrigation or recycling in the artichoke processing industry.

The main exploring studies of integrated membrane systems have been developed in Europe to provide a suitable solution for the disposal of OMWWs, AWWs, and OPL. Until 2015, there was no proposal to counteract the large amounts produced of WWs in the American continent by using membrane processes. The R & D is mainly focused on the Nixtamalization wastewaters (NWWs) regarding their disposal. This WW is produced by a common processing step given to the maize; which is carried out in almost all America, the Nixtamalization treatment. It is important to note that a production plant (in Mexico) with capacity of 600 Ton maize per day generates around 2000 m^3 of the extract (Salmeron-Alcocer *et al*., 2003). If this WW production is interpolated to all Mexico or even to all America, it is clear the big challenge that we have to face. Nowadays, Castro-Muñoz, Orozco-Álvarez, Cerón-Montes, and Yáñez-Fernández (2015b) proposed the first attempt of membrane technology (MF) for the treatment of

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Table 1. Water streams obtained from the treatment of WWs by integrated membrane systems.

Agro-food by-product:	Integrated membrane process conformed by: (Membrane operation: MWCO)	Water sample obtained:	Characteristics of permeates:	Reference:
Olive mill wastewater	UF: 0.2 μm UF: 1 000 Da NF: > 97% $MgSO_4$ rejection		Low TOC: 95 mg l^{-1} Low TC: 100 mg l^{-1} Low TIC: 5 mg l^{-1} Hydroxytyrosol: 0 mg l^{-1} (N.D.) Caffeic acid: 0 mg l^{-1} (N.D.) p-cumaric acid: 0 mg l^{-1} (N.D.) Tyrosol: 0 mg l^{-1} (N.D.) Catechol: 0 mg l^{-1} (N.D.) Protocatechuic acid : 0 mg l^{-1} (N.D.) Total phenols: 0 mg l^{-1} (N.D.)	Cassano *et al*., 2013
Orange press liquor	UF: 100 kDa NF: 25-50% Na_2SO_4 rejection	Not reported	Low TSS: 4.5 g 100 g^{-1}	Cassano *et al*., 2014
Artichoke wastewaters	UF: 50 kDa NF: 400 Da, 85-95% Na_2SO_4 rejection NF: 150-300 Da, 96% $MgSO_4$ rejection	Not reported	Glucose: 0 mg l^{-1} (N.D.) Fructose: 0 mg l^{-1} (N.D.) Sucrose: 0 mg l^{-1} (N.D.) Cynarin: 0 mg l^{-1} (N.D.) Chlorogenic acid: 0 mg l^{-1} (N.D.) Apigenin-7-O-glucoside: 0 mg l^{-1} (N.D.)	Conidi *et al*., 2014
Artichoke wastewaters	UF: 100 kDa NF: 400 Da, 85-95% Na_2SO_4 rejection NF: 150-300 Da	Not reported	Glucose: 0 mg l^{-1} (N.D.) Fructose: 0 mg l^{-1} (N.D.) Sucrose: 0 mg l^{-1} (N.D.) Cynarin: 0 mg l^{-1} (N.D.) Chlorogenic acid: 0 mg l^{-1} (N.D.) Apigenin-7-O-glucoside: 0 mg l^{-1} (N.D.)	Cassano *et al*., 2015
Nixtamalization wastewaters	MF: 0.2 μm UF: 100 kDa UF: 1 000 Da		Low TOC: 381 mg l^{-1} Low Carbohydrates content: 0.26 mg ml^{-1} Low turbidity: 3.78 NTU Free TSS: 0 ºBrix (N.D.)	Castro-Muñoz *et al*., 2015a-d; Castro-Muñoz *et al*., 2016b

TOC: Total Organic Carbon; TC: Total Carbon; TSS: Total Soluble Solids; TIC: Total Inorganic Carbon; N.D.: Not detected.

NWWs in order to decrease their TOC content. The evaluation to recover valuable compounds (carbohydrates) was also tested by using ultrafiltration (Castro-Muñoz, Cerón-Montes, Barragán-Huerta, & Yáñez-Fernández, 2015c). Finally, the sequential design of the membrane processes was successfully applied obtaining highlighted results; the rejection of calcium components was performed (Castro-Muñoz & Yáñez-Fernández, 2015d; Castro-Muñoz, Barragán-Huerta, Yáñez-Fernández, 2016b). Indeed, the final water stream was clear which presented low turbidity and TOC content (see table 1). The authors found high polyphenol content in the samples where additional recovery steps were suggested; however; this clear stream can be used as process water in following Nixtamalization processes.

Finally, table 1 shows the permeate samples obtained from Cassano *et al.* (2013) and Castro-Muñoz & Yáñez-Fernández (2015d) in their respective cases of study. Cassano *et al.* (2013) achieved to obtain a stream totally clear; whereas Castro-Muñoz produced a clear permeate with low turbidity. The difference of both studies can be attributed to the specific membranes used;

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nanofiltration and ultrafiltration membranes; respectively. Nevertheless; the use of narrow pore size membrane (1 kDa) is also a useful tool because this specific barrier is considered as the border of nanofiltration (Galanakis, 2015). Thereby, we can see that few applications of IMPs have been successfully developed. This current proposal seems to be suitable for the reduction of WW, providing a feasible possibility for re-processed them. Indeed, the utilization of IMPs has come to solve the final disposal of common WWs in the European Union; it can be an amazing tool for America too. The objectives are perfectly aimed to:

- Treat the WWs to decrease their COD.
- Recover the high-added value compounds from the WWs.

The last subjects have been successfully achieved and demonstrated; however, an extra plus was also discovered, which could be strongly the most important: *The water production*. A sustainable scheme can be proposed according to this revision, as figure 1 shows.

The recovery of valuable compounds trough the WW treatment provides a result on reducing the COD in the by-products. This point of view can offer an outlook to the industries regarding waste disposal and economic aspects. The high-added value solutes (sugars, pectins, proteins, polyphenols) commonly recovered from wastes are of interest for food and pharmaceutical industries; the application of the membrane technology represents a feedback option at least economically. Also, the reuse of produced water is a real possibility to demonstrate a sustainability concept: *Industry-Environment-Society*. The integrated membrane systems represent a valuable methodology for making the complete task by developing a "*Sustainable Recovery Process*".

General remarks

The water care is a current problem that concerns to the society, while researchers are en-

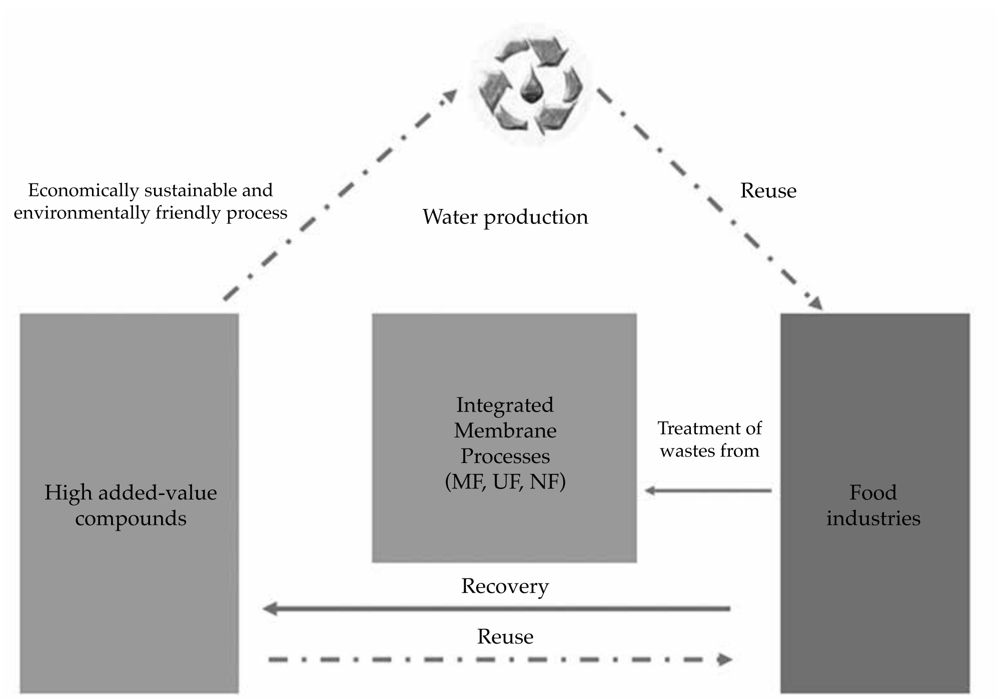

Figure 1. Sustainability of the IMPs through the water recovery.

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couraged to attend this global issue looking for new helpful technologies. At least, the treatment of food processing wastewaters can be solved if the application of membrane technology is well done. Also, the Food processing industries must start to consider their wastes as potential sources for useful components; the wine-making industry seems to be a consolidated trade that use its by-products for recovering valuable phenolic compounds (Crespo & Brazinha, 2010). Nowadays, R&D is looking for new sustainable methodologies and the revised studies demonstrate that the recovery of valuable solutes could offer the chance to obtain *water for recycling*. The IMP is a new development that has to continue being explored. Likewise, the future trends should be focused in this field because the food production demand is always increasing (Bennett, 2015). Finally, the economic investment concerns to the industries, the application of the IMP approaches is economical and environmentally sustainable, and their benefits will be reflected remarkably soon.

Abbreviations

Microfiltration: MF
Ultrafiltration: UF
Nanofiltration: NF
Wastewaters: WW
Olive mill wastewater: OMWW
Artichoke wastewater: AWW
Orange press liquor: OPL
Nixtamalization wastewaters: NWW
Chemical oxygen demand: COD
Integrated membrane process: IMP
Molecular weight cut-off: MWCO
Total organic carbon: TOC
Total soluble solids: TSS
Total carbon: TC
Total inorganic carbon: TIC
Not detected: N.D.

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