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Integrating membrane technologies and blending options in water production and distribution systems to improve organoleptic properties. The case of the Barcelona Metropolitan Area

Jordi Raich-Montiu [a,*], Joan Barios [a], Veronica Garcia [b], Maria Eugenia Medina [c], Fernando Valero [c], Ricard Devesa [b], Jose Luis Cortina [a]

[a] CETaqua, Water Technology Center, Carretera d'Esplugues 75, 08940 Cornellà de Llobregat, Spain
[b] Aigües de Barcelona (AGBAR), Laboratori, General Batet, 5-7, 08028 Barcelona, Spain
[c] Aigües Ter-Llobregat (ATLL), Sant Martí de l'Erm, 30, 08970 Sant Joan Despí, Barcelona, Spain

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ABSTRACT

The Barcelona Metropolitan Area (BMA) drinking water supply network has been based on surface water resources for decades. Those resources have experienced anthropogenic and environmental pressures, reducing their quantity and quality. Consequently, new infrastructure was built to improve the drinking water quality and to ensure the availability of the resources in recent years. Two drinking water treatment plants treating surface water with high salinity (e.g., total dissolved solids of approximately 900 mg/L) from the Llobregat River, incorporated membrane technology (reverse osmosis in one case and reverse electrodialysis in the other case) to reduce the salinity levels. Additionally, a reverse osmosis sea water desalination treatment plant was built to avoid a lack of water, particularly during periods of extreme drought. The system was completed with a new distribution network interconnecting different resources to blend the water and achieve a high and uniform organoleptic water quality in the area. This study characterised the organoleptic quality of the water under this new scenario that integrates new water sources and blending options along the distribution zones of the BMA. The effect of membrane technologies (reverse osmosis and reverse electrodialysis), the influence of the type of water source on the disinfection by-product formation and water aggressiveness toward the network materials were also assessed. The membranes improved the water flavour and reduced the disinfection by-product formation potential and aggressiveness compared to conventional treatment. In addition, the water quality became less dependent on its source; if hydraulically possible, operation criteria could be defined to promote blends along the reservoirs and the network to improve and unify the organoleptic properties.

1. Introduction

In recent decades, the Barcelona Metropolitan Area (BMA) drinking water supply network has been primarily based on surface water resources. Those resources are suffering the effects of mining and industrial discharges, as well as a reduction in quantity, decreasing the quality of the raw water. Additionally, due to the Mediterranean climate, the natural water resource availability is periodically lower than the water demand in the area. Drought is a cyclical and recurrent phenomenon in the catchment areas that provide water to urban Barcelona. Since 1982, drought alerts have been declared every two or three years because the current water storage capacity is rather limited. The average yearly demand is very similar to the average yearly rainfall, which is very close to the total storage capacity installed. Consequently, low rainfall years usually bring the system to the verge of collapse. This situation

List of acronyms: ATLL, Aigües Ter-Llobregat; BMA, Barcelona metropolitan area; DBPs, disinfection by-products; DWTP, drinking water treatment plant; ECD, electron capture detector; FPA, flavour profile analysis; GAC, granular activated carbon; HRGC, high resolution gas chromatograph; ICP-MS, inductively coupled plasma mass spectrometry; L/L, liquid–liquid extraction; LSI, Langelier saturation index; NF, nanofiltration; NOM, natural organic matter; RED, reverse electrodialysis; RO, reverse osmosis; SGAB, Sociedad General de Aguas de Barcelona; SWDTP, sea water desalination treatment plant; *t*, time; THMs, trihalomethanes; THMs-FP, trihalomethanes formation potential; TOC, total organic carbon; UF, ultrafiltration; USEPA, United States Environmental Protection Agency; WHO, World Health Organization.

* Corresponding author.
E-mail address: jordiraich@gmail.com (J. Raich-Montiu).

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requires alternative resources to ensure the drinking water supply across the entire water network.

Membrane technologies have been identified as the most robust and flexible technologies used to improve water quality and taste by removing undesirable compounds and pathogens (Wang et al., 2006, Reverberi and Gorenflo, 2007, Rahardianto et al., 2007). Reverse osmosis (RO), nanofiltration (NF) and reverse electrodialysis (RED) are being applied worldwide to meet these needs (Wang et al., 2006, Greenlee et al., 2009; Birnhack et al., 2011). The selection of a suitable membrane technology is based on technical criteria (removal of contaminants) and economic aspects (capital operation and maintenance).

The two BMA drinking water treatment plants (DWTPs) that treat high salinity surface water (e.g., up to 900 mg/L) were modified by incorporating a membrane step (RO in one case and RED in the other case). Additionally, a sea water desalination treatment plant (SWDTP) using RO was built to mitigate the lack of water, particularly during extreme drought episodes. The quality of unconditioned membrane desalinated water can vary significantly, depending both on the type of technology used for salinity removal and on the specific design and operation of the desalination process (Withers, 2005; Shizari et al., 2012). In addition, membrane technologies both remove and reduce dissolved organic matter content and disinfect by-products precursors (Taylor et al., 2005). For low quality surface waters, such as that from the Llobregat River Basin, these characteristics are particularly important. The high salinity content, including halogenate ions (bromide and iodide), combined with the presence of dissolved organic matter and chlorination induces the formation of trihalomethanes (THMs), with concentrations close to the legislated values. Membrane technologies reduce the THM precursors, such as organic matter, bromide and iodide, to reduce their concentration in the water distribution network.

According to the World Health Organization (WHO, 2000), THMs are the most abundant disinfection by-products (DBPs), and the United States Environmental Protection Agency (USEPA) has stated that they were human carcinogens (USEPA, 1999). These compounds have been regulated in the European Union since 1998 (Directive, 98/83/EC) and transposed into Spanish legislation in 2003 (RD 140/2003) with a provisional parametric value of 150 μg/L that was reduced to 100 μg/L on January 1st, 2009.

In a common scenario, when NF, RO and RED are used, a post-treatment step of remineralisation with limestone filters or with lime/carbon dioxide saturators is carried out (Kettunen and Keskitalo, 2000; Hasson and Bendrihem, 2006; Birnhack et al., 2011). However, for SWDTPs, it is crucial to achieve water quality requirements even when low water aggressiveness is common in the network with Langelier Index values between −0.5 and 0.5 (Birnhack and Lahav, 2007). Once water enters the distribution systems, it can corrode pipelines and become enriched in trace metals. The pH and water hardness values are key parameters that control corrosion (Plottu-Pecheux et al., 2001). Acidic waters are much more corrosive or aggressive than hard water in piping systems. Corrosion episodes occurred in other similar cases after blending different water sources (Tang et al., 2006; Alshehri et al., 2009), particularly when membrane technologies had been incorporated onto the potable water production works. For distribution systems using surface waters, improving the mineralogical water quality could also be achieved by the blending the membrane permeates after remineralisation with treated water that has undergone conventional treatment (Lahav et al., 2009). For BMA, the pipes interconnecting the infrastructures and water reservoirs to increase the blending options were built as an alternative to distribute the best water quality with the highest taste uniformity. Drinking water taste is normally determined by public opinion as an indicator of its quality (Levallois et al., 1999). Previous works have demonstrated the usefulness of the information that tasting panels can provide to water companies (Morran and Marchesan, 2004; McGuire et al., 2007). Water taste preferences in the BMA distribution network were known before the membrane treatment technologies were installed. Treated water from the Ter River (with total dissolved solids of approximately 350 mg/L) also supplying water to the BMA was more accepted than from the Llobregat River; therefore, optimal blends between both sources had been studied (Fabrellas et al., 2004). Therefore, implementing new membrane technologies to treat raw water, reducing the saline content, with subsequent remineralisation, significantly improved the water flavour (Yeh et al., 2000; Peltier et al., 2002). However, in such complex systems with several sources and blends, new approaches including new chemometric tools to determine the relative amounts of water blends at the tap water were developed in addition to the standard organoleptic characterisation methodologies (Platikanov et al., 2011). These studies were performed on the laboratory scale by preparing blends to reproduce the potential mixtures to be generated in the network while managing the circumstances and hydraulic operation criteria. Therefore, different studies have been carried out (Bruchet and Lainé, 2005; Devesa et al., 2007; García and Devesa, 2009) to characterise the organoleptic properties of water blends integrating different water resources qualities and drinking water treatment plants incorporating membrane technologies.

Currently, the use of desalination technologies has been increasing dramatically in the BMA and in Catalunya in recent years (Domènech et al., 2013). This study addressed how the membrane treatment technologies and blends affect the organoleptic properties of water, concentration and formation potential of THMs (THMs-FP) and aggressiveness. To this end, several different key sampling points were used to cover a wide variety of water samples from the water distribution network with different sources (two types of surface water and sea water), and the treatments (conventional and membrane technology) were defined in close coordination with the operators along the BMA distribution network. Accounting for the seasonal influence on surface water quality and DWTP operating conditions is important (Proulx et al., 2012), and campaigns were conducted during winter and summer. The results of this work are expected to be useful to other distribution networks with similar complexities.

2. Materials and methods

2.1. Barcelona Metropolitan Area: site description

Urban Barcelona extends covers 635 km^2 and has a population of 4.5 million, accounting for approximately 44% of the population in Catalonia. The city, as well as its urban area (referred to as Barcelona Metropolitan Area), draws its water supply from the Ter and Llobregat Rivers as described in Fig. 1. These two rivers have a combined reservoir capacity of 612 hm^3. The surface water constitutes around the 85% of the total water supplied in BMA, while the last 15% of the water comes from sea water and groundwater resources.

Two DWTPs treating water from the Llobregat River (with high salinity content with total dissolved solids of approximately 900 mg/L due to its course through a salt mining basin) were modified to incorporate a membrane step (RO in one case and RED in the other case) to reduce the salinity and dissolved organic matter. In 2008, a drought season caused a scarcity of drinking water resources, leading to a search for alternative resources to ensure the drinking water supply. A Sea Water Desalination Treatment Plant using reverse osmosis was built to ensure the