Multicriteria evaluation of novel technologies for organic micropollutants removal in advanced water reclamation schemes for indirect potable reuse.

C.Echevarría [a], I.Martín [a], M.Arnaldos [a], X.Bernat [a], C.Valderrama[b], J.L. Cortina[b].

[a] *CETaqua, Water Technology Center*
[b] *Technical University of Catalonia (UPC). Chemical Engineering Department.*
**cechevarriadc@cetaqua.com*

INTRODUCTION

Indirect potable reuse (IPR) refers to the addition of purified reclaimed water into a water body (surface water augmentation or groundwater recharge) in order to store it and reuse it as drinking water supply. The application of this system represents a sustainable management of an alternative water resource following the circular economy framework that allows to preserve conventional freshwater resources. One possibility in IPR schemes is the deep well injection of reclaimed water for groundwater replenishment systems (GWRS) or also the prevention of saline barrier intrusion in those coastal regions with overexploitation of groundwater. However, the presence in urban and industrial wastewaters of compounds of anthropogenic origin that are called organic micropollutants (OMP), their unknown effects on public health post-catchment in water treatment plants and the concern associated in public authorities & population represent additional drawbacks in the implementation of IPR schemes. In order to guarantee the removal of these compounds, it is necessary to resort to advanced water reclamation technologies, focused on the removal of these recalcitrant compounds, usually not removed completely in conventional wastewater treatment schemes (Alvarino et al. 2018; Cabeza et al. 2012).

Reverse Osmosis (RO), due to its molecular weight cut-off (200-300 Da), is able to remove efficiently the majority of OMP present in urban wastewaters (300-400 Da) apart from a complete removal of salinity, nutrients and organic matter; nevertheless, its efficiency is also associated to a high treatment cost (Verliefde 2008). Usually, in these advanced reclamation schemes, microfiltration (MF) or ultrafiltration (UF) are used as pre-treatment in order to guarantee a free suspended solids (SS) and disinfected influent. Moreover, in case legislation and/or quality requirements allow it, the pre-treatment (MF/RO) and the RO effluents are blended 50% to reduce the overall treatment costs. On the other hand, hybrid technologies represent an alternative to remove efficiently OMP by avoiding the use of RO (and its high energy cost associated) through the combination of different removal technologies. Powdered activated carbon (PAC)-nanofiltration (NF), for example, combines the adsorption potential of PAC with membrane separation provided by a capillary hollow fiber (HF)-NF. Other possibilities are the combination of advanced oxidation systems with membrane technologies or the use of adsorbent filters (usually granular activated carbon (GAC)) or biofilters as final polishing steps.

The aim of this research is to compare from a technical and economic point of view the use of UF/RO systems and hybrid systems based on PAC-NF in order to remove efficiently OMP from wastewater effluents and use the reclaimed water for groundwater replenishment and as a barrier against aquifer salinization.

MATERIALS & METHODS:

During 18 months a prototype composed by a PAC contact tank and two capillary HF-NF modules was operated in "El Baix Llobregat" water reclamation plant (WRP) in order to characterize water quality, obtain optimal operating conditions and compare it from a technical-economic point of view with the full-scale plant (15000 m^3/d) UF-RO (50% blend) used for aquifer recharge. PAC-NF prototype (2 m^3/h) was fed with a MBR prototype (3 m^3/h) effluent, which performance and technical evaluation will remain out of the scope of this study. HF-NF modules (PES; MWCO: 1000 Da) are chlorine tolerant and were operated in inside-out configuration, with a baseline internal recirculation (crossflow) of 12 m^3/h. Due to its MWCO, no salinity removal is obtained. The UF-RO (50% blend) full-scale plant was fed from a conventional basic reclamation (BR) system based on a physico-chemical treatment followed by ballasted sedimentation, disk-filtration and UV disinfection.

The prototype performance was compared with data (hydraulic and energy) gathered from the full-scale UF-RO. In addition, several campaigns were carried out to establish a water quality monitoring of the different streams. 17 OMP were selected as target analytes representing a wide range of micropollutants occurring in wastewaters. Solid phase extraction (SPE) coupled online with liquid chromatography and tandem mass spectrometrhy (LC-MS/MS) with electrospray ionization was used to quantify OMP. These 17 OMP included **9 pharmaceuticals**, **6 pesticides** and **2 alkylphenols**.

RESULTS:

In terms of OMP removal, due to the MWCO (1000 Da), tested HF-NF membrane did not represent a physical barrier to these compounds and the addition of PAC allows the major part of the adsorption. No significant variations were found in the removal of target compounds regarding the different tested PAC dosages (20, 50, 100 mg/L) .Due to the high cost associated to PAC (2-5 €/kg), and according to resulting water yield & energy demands, **low PAC dosage (20 mg/L) was defined as the optimal to operate** in a sustainable way the hybrid HF-NF system.

Figure 1 aims to compare the removal efficiencies of conventional advanced wastewater treatment and reclamation systems with the hybrid system tested. RO membranes, due to the MWCO represented a physical barrier to OMP and high removal efficiencies (beyond 90-95%) were obtained for most of detected compounds. Since OMP removal efficiencies obtained through UF are very low (5-15%), the UF-RO (50% blend) system reported removal efficiencies between 40-50%. On the other hand, PAC-NF system allowed higher average removal efficiencies (50-70%) for most of detected OMP.

Operational expense (OPEX) (including chemicals, energy and membrane replacement) and capital expense (CAPEX) were evaluated for both advanced water reclamation systems, both sized for a 15000 m^3/d of capacity. Due to the high inlet pressure in RO membranes (10 bar approximately), energy demand of UF+RO (0.70 kWh/m^3) is twice that of PAC-NF (0.35 kWh/m^3). In terms of chemical consumption, due to the continuous PAC dosing, PAC-NF system is a 90% higher (191 Tn/year) than UF+RO (50%) (101 Tn/year). Operational costs of 0.20 and 0.25 €/m^3 were obtained, respectively for UF+RO and PAC-NF systems. The higher cost of PAC-NF is mainly associated to the high cost of PAC, which in this study was considered 2€/kg. Due to the lower water yield, PAC-NF generates a higher volume of brines, nevertheless, the conductivity of these brine allows to return it to headworks. On the contrary, for RO brines, it is necessary to manage it with the submarine emissary. CAPEX was also assessed resulting in 9 M€ for UF-RO plant (50% blend) and 8 M€ for PAC-NF plant. Finally, in terms of environmental impact, the use of PAC has a negative impact in the carbon footprint (0.72 kg CO_2/m^3), resulting to be around 3 times higher than in the UF+RO system (0.24 kg CO_2/m^3).

CONCLUSIONS:

From a technical point of view, OMP removal efficiencies for the different treatment schemes showed that the hybrid system PAC-NF allows average removal efficiencies between 50 and 70% regarding the inlet (MBR) concentration while efficiencies between 40-50% were obtained from UF-RO (50% blend) system.

As it is shown in Table 1 two applications for the implementation of these two treatment schemes were proposed. PAC-NF could be an interesting alternative to UF-RO in IPR in inland zones (in case salinity removal is not required and there is a proper nitrification-denitrification upstream). In addition, despite a higher OPEX (0.25 €/m^3) and carbon footprint associated, the possibility of returning brines generated headworks is associated to economic savings in brine management and can be also perceived as an environmental driver. On the other hand, in coastal areas, where brine management is not an issue since marine disposal is the main alternative, UF-RO (50% blend) seems to be more suitable due to its lower OPEX (0.2 €/m^3). Additionally, in coastal areas with groundwater overexploitation, saline intrusion in aquifers is a recurrent problem and the deep well injection of purified reclaimed water with salinity reduction (obtained through RO membranes) is used as artificial barrier in order to preserve groundwater reservoirs from salinization.

Table 1 Implementation costs of both advanced water reclamation schemes.

Application (reuse)	**Coastal areas** (Saline Intrusion Barriers)	**Inland areas** (IPR – GWR or Surface water augmentation)
Water Quality limitations	Salinity removal-reduction	Nutrients removal
Advanced Water Reclamation Scheme	UF+RO (50% blend)	PAC-NF (20 mg/L)
Average removal of recalcitrant OMP	40-50%	50-70%
Brine generation [m^3/d]	3750 (marine disposal)	4350 (return to headworks)
OPEX [€/m^3]	0.20	0.25
CAPEX [M€]	9	8
Carbon footprint [kg CO_2/m^3]	0.24	0.72

FIGURES:

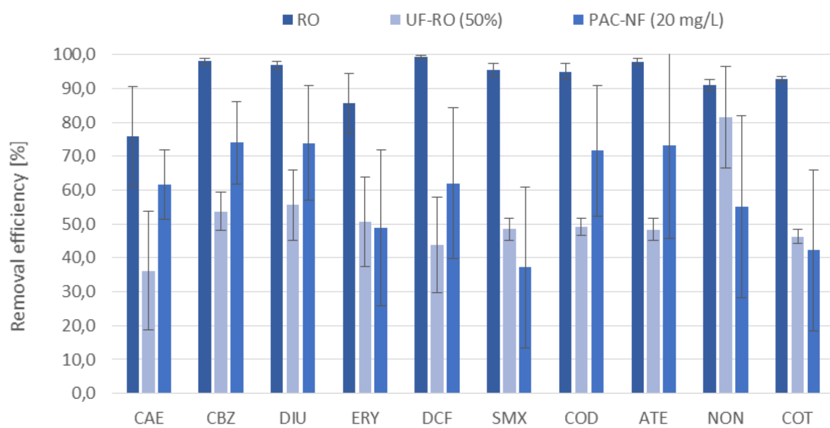

Figure 1 Comparison of OMP removal efficiencies between PAC-NF system and conventional advanced water reclamation systems RO & UF-RO(50%)

REFERENCES:

- Alvarino, T., S. Suarez, J. Lema, and F. Omil. 2018. "Understanding the Sorption and Biotransformation of Organic Micropollutants in Innovative Biological Wastewater Treatment Technologies." *Science of The Total Environment* 615: 297–306. https://doi.org/10.1016/j.scitotenv.2017.09.278.
- Cabeza, Y., L. Candela, D. Ronen, and G. Teijon. 2012. "Monitoring the Occurrence of Emerging Contaminants in Treated Wastewater and Groundwater between 2008 and 2010. The Baix Llobregat (Barcelona, Spain)." *Journal of Hazardous Materials* 239–240: 32–39. http://dx.doi.org/10.1016/j.jhazmat.2012.07.032.
- Verliefde, Arne. 2008. "Rejection of Organic Micropollutants by High Pressure Membranes (NF/RO)." TU Delft.