aWARE

Innovative hybrid MBR systems to promote Water Reuse

http://www.life-aware.eu/

LIFE aWARE
Reutilización para la eliminación de compuestos prioritarios y emergentes

Workshop Impulsando la reutilización en el ciclo integral del agua
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Nacho Martin Garcia
Cetaqua, Centro Tecnologico del Agua, Barcelona, Spain.

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LINEX

Life

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LIFE aWARE: objectives

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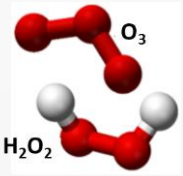
The overall objective of the LIFE aWARE project is to **promote water reuse** by consolidating knowledge about a wide range of water reclamation technologies and identifying key issues regarding the production, demand and distribution of reclaimed water.

Water reclamation technologies focused on removal of PP and CEC



ADVANCED OXIDATION PROCESSES

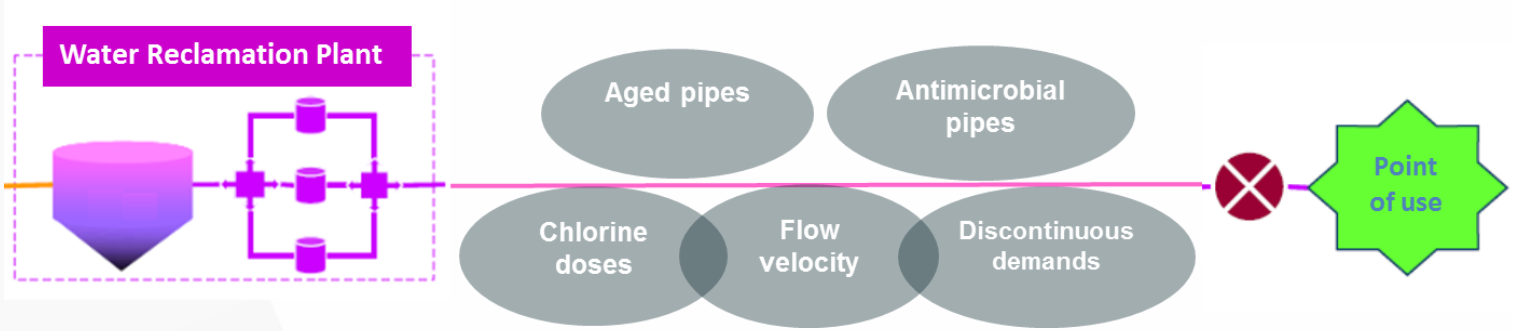
REVERSE OSMOSIS/NANOFILTRATION

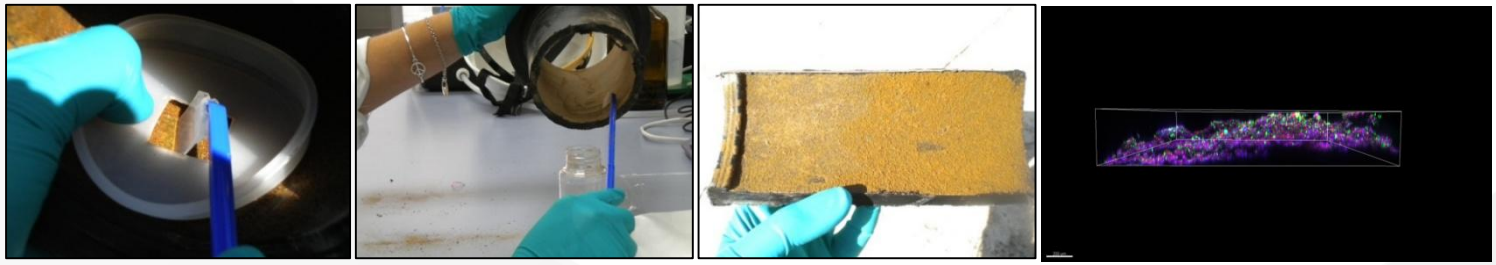
ACTIVATED CARBON

Management of reclaimed water distribution networks

Distribution of reclaimed water: Objectives and scope

To idenify the main **factors that influence the development of biofilm** in distribution networks of reclaimed water and to evaluate under controlled conditions biofilm characteristics in order to contribute to the develoment of **strategies that guaranty water quality** in point of use.





Experimental and analytical plan

Distribution network prototype

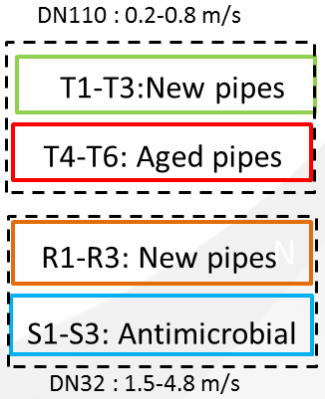
Microbial parameters in biofilm

- *E.Coli* and *T.Coli*
- *Legionella pneumophila*
- *P.Aeruginosa*

Biofilm characteristics

- Polysacharides content
- Epifluorescence (total bacterial count)
- Cell vibility (Live/dead)
- Confocal microscopy (biofilm thickness and structure)

				Chlorine dose 1 (4 months)	Chlorine dose 2 (4 months)
Branch nº	Element	Flow (m^3/h)	Diameter (m)	Velocity (m/s)	Velocity (m/s)
1 Low flow	T1-T4	5.5	DN110	0.21	0.21
Discontinuos demand	S1-R1	4.3	DN32	1.49	1.49
2. Low flow	T2-T5	5.5	DN110	0.21	0.21
Continuos demands	S2-R2	4.3	DN32	1.49	1.49
3 High flows	T3-T6	21	DN110	0.79	0.79
Continuos demands	S3-R3	10-14	DN23	4.84	3.45



Distribution network results

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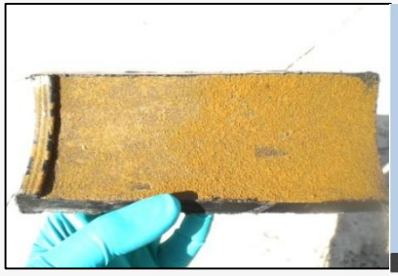
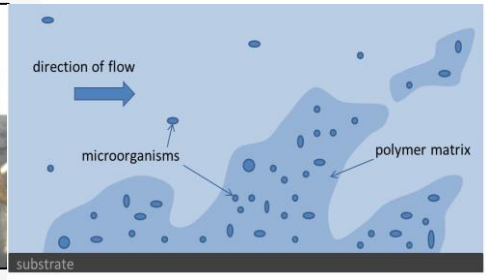
Main results





Microbiology of biofilm :

- *Across the different conditions and elements tested (12 in total) Legionella pneumophila was not found colonizing biofilm*
- *E.Coli was found in 4/6 of the samples with velocities below 0,8 m/s and in only 1/6 samples for the velocities of 1,5 m/s or above.*
- *Of the positive samples (5 in total), 4 were quantified below 10 CFU/cm^2 being between 1-2 orders of magnitude lower than T.Coli and 2-3 in comparison to P.aeruginosa*

Distribution network operational parameters :

- *Between 1 and 3 log units higher bacterial counts found at the velocity of 0,8 m/s in comparison to lower (0,2 m/s) and higher velocities (1,5 m/s)*
- *Between 1 and 3 log units higher bacterial counts found with discontinuous operation in comparison to continuous*

Distribution network operational elements :

- *No clear trends for aged pipes in comparison to new or antimicrobial pipes in comparison to conventional. Antimicrobial pipes generated thinner biofilms, with higher cell viability and lower EPS content*

Technologies for removal of priority and emerging contaminants

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To conduct a **techncial, economic and environmental comparsion** of **water reclamation techncologies based on** the use **Powdered Activated Carbon (PAC) and Advanced Oxidation Processes (AOPs)** as an **additional barrier for priority and emerging contaminants**

MBR-PAC-NF PROTOTYPE

Membrane bioreactor (MBR)

Powdered Activated Carbon

Nanofiltration (NF)

Economic (LCC)
Environmental (LCA)
Techncial assesment

Operation

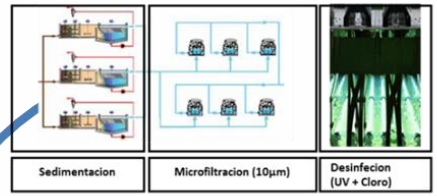
- Membrane performance

Water quality

- Reuse parameters (RD1620/2007)
- Microbiological parameters
- PP, CEC, metals

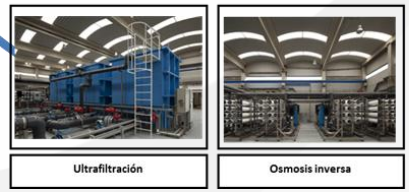
BLL WATER RECLAMATION PLANTS

Basic Water Reclamation



Advanced Oxidation Processes

Advanced Water Reclamation



Technical programme: Advanced Oxidation Prototype

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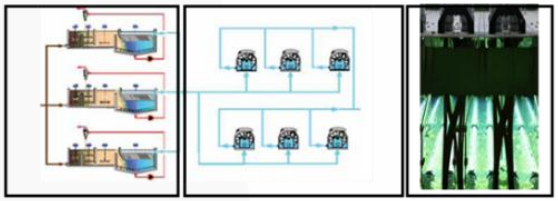
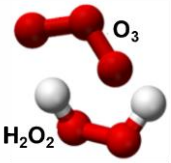
Advanced Oxidation procecess (AOPs)

Basic Water Reclamation Plan



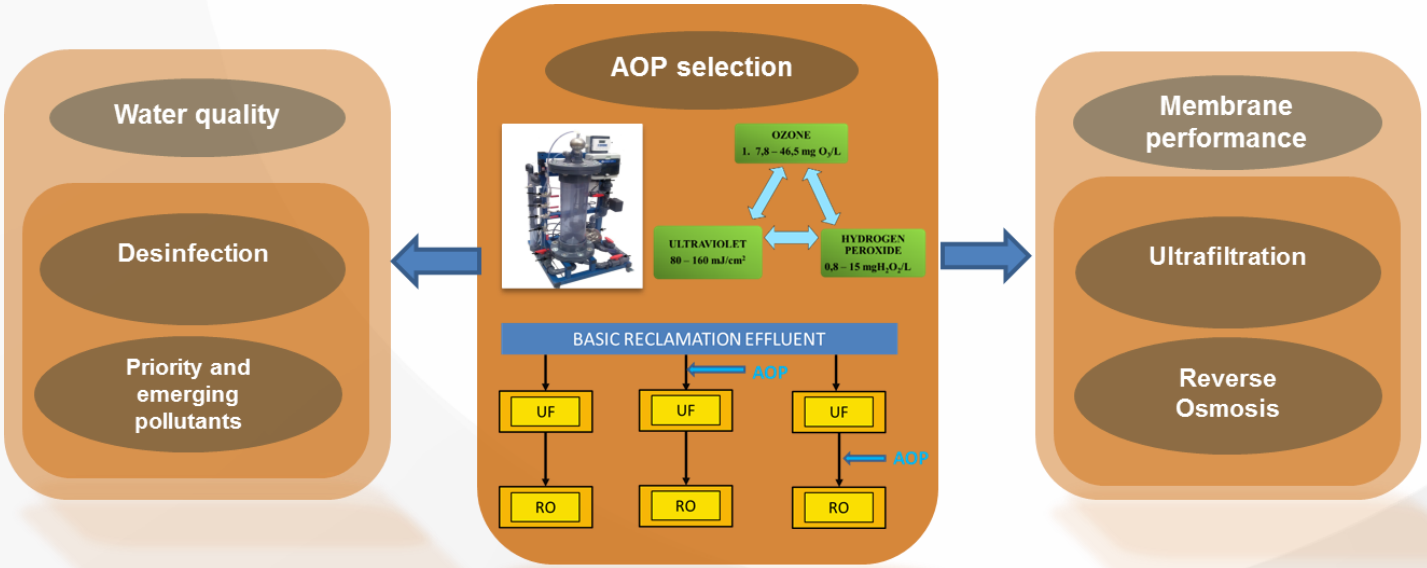
Sedimentacion | Microfiltracion (10µm) | Desinfecion (UV + Cloro)



Ozone + UV

Advanced Water Reclamation Plant

Ultrafiltración | Osmosis inversa



Technical programme: MBR-PAC-NF prototypes

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Membrane bioreactor (MBR)

Powdered Activated Carbon

Nanofiltration (NF)

18 months operation
1.No PAC in MBR
2. PAC in MBR

PAC-MBR CHARACTERISTICS-OPERATION	
Containerized 40 feet , automatic operation 24h / 7d	
Treatment capacity	50-60 m^3/d
MBR operation	HRT: 9 -12 hour Waste: 300-500 L/d MLSS : 8-12 gSS/L PAC: 0,6-1,2 g/L
Membrane configuration	2 X Multitubular UF (UF1 and UF2)
Membrane área	33 m^2/module
Fibre internal diameter	5,2 mm
MWCO:	20 nm
Material	PVDF
Standard production	1,4- 2 m^3/h
Operation **Airlift inside-out filtration**	Air sparging rate: 8-10-15 m^3/h Crossflow pump rate:15 m^3/h Filtration duration: 8-10 min Hydraulic cleanings: BW and drain Chemical cleaning: Oxidant (500 ppm NaOCl),acid (citric 0,5 %)

Operation and monitoring:

- **Membrane optimization** for flux, energy demands, PAC doses (25,50,100 mg/L)
- Monitoring energy, demands, sludge production and use of chemicals for membrane cleaning and P removal
- **Water quality analyses:**
  - Water Reuse parameters
  - Microbiological parameters
  - PP, CEC and metals
  - Silt density index (SDI)

PAC-NF CHARACTERSITICS AND OPERATIONAL CONDITIONS	
Containerized 40 feet , automatic 24h / 7d	
Treatment capacity	50 m^3/d
PAC	Contact time: 30 min – 2h Dose: 10 -100 mg/l
Membrane configuration	Capillary inside-out filtration
Membrane área	40 m^2/module
Fibre internal diameter	0,8 mm
MWCO:	1000 Da
Material	PES
Standard production	0,8-1,5 m^3/h

Operation
 	
Presurrized internal recirculation
	• Fluxes: 15-30 LMH
	• Internal recirculation:0-4-12 m^3/h
	• Water recovery :50-60-75 %
	• Filtration duration: 30-60-240 min
	• Hydraulic cleanings:
	  • Forward flush
	  • Backwash
	• Chemically Enhanced Forward Flush:
	  • Oxidant: NaOCl :250 ppm
	  • Acid: citric: 0,5 %

Results of the impact of AOPs and PAC on membrane performance

Main results

Influence of PAC in MBR and NF fouling

- ***PAC reduced fouling rates by 40 % in MBR.***

However UF operated at similar conditions (fluxes and energy) demands with and without PAC

- ***NF membrane operational conditions identified at different PAC concentrations***
  - *25 mg PAC/L: 20 LMH , hydraulic cleaning every 60 min (71 % conversion)*
  - *50-100 mg PAC/L: 20 LMH , hydraulic cleaning every 15-30 min (50 % conversion)*

Influence of MBR and NF as pretreatment of RO

- *MBR: 70 % of SDI: 1.5 – 3 and PAC-MBR: 99 % of SDI: 1.5-3*
- *NF: 86 % of SDI: 1- 3 and PAC-NF : 80 % of SDI: 1-3*

Influence of AOPs applied to basic WRP as pretreatment of UF and RO

- *Fouling rate reduction of 30 % in the UF in comparision to basic WRP*
- *No influence observed for RO*

MBR-PAC-NF results

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Powdered Activated Carbon

Membrane bioreactor (MBR)

Nanofiltration (NF)

Parameter (Unit)	MBR	PAC-MBR	Basic WRP
COD (mg-O_2/L)	22 - 28	24- 28	27-32
BOD_5 (mg-O_2/L)	< 1- 1.4	< 1- 2.4	2-3
TN (mg-N/L)	11-15	9- 12	7-9
TP	-	0.3-1.5	1-1.9
SS (mg/L)	<1	<1	1-4
Turbidity (NTU)	0.5-0.8	0,5 - 0,7	1-2
E.Coli (CFU/100 mL)	<1	<1	<1
Legionella (CFU/L)	< 100	<100	<100

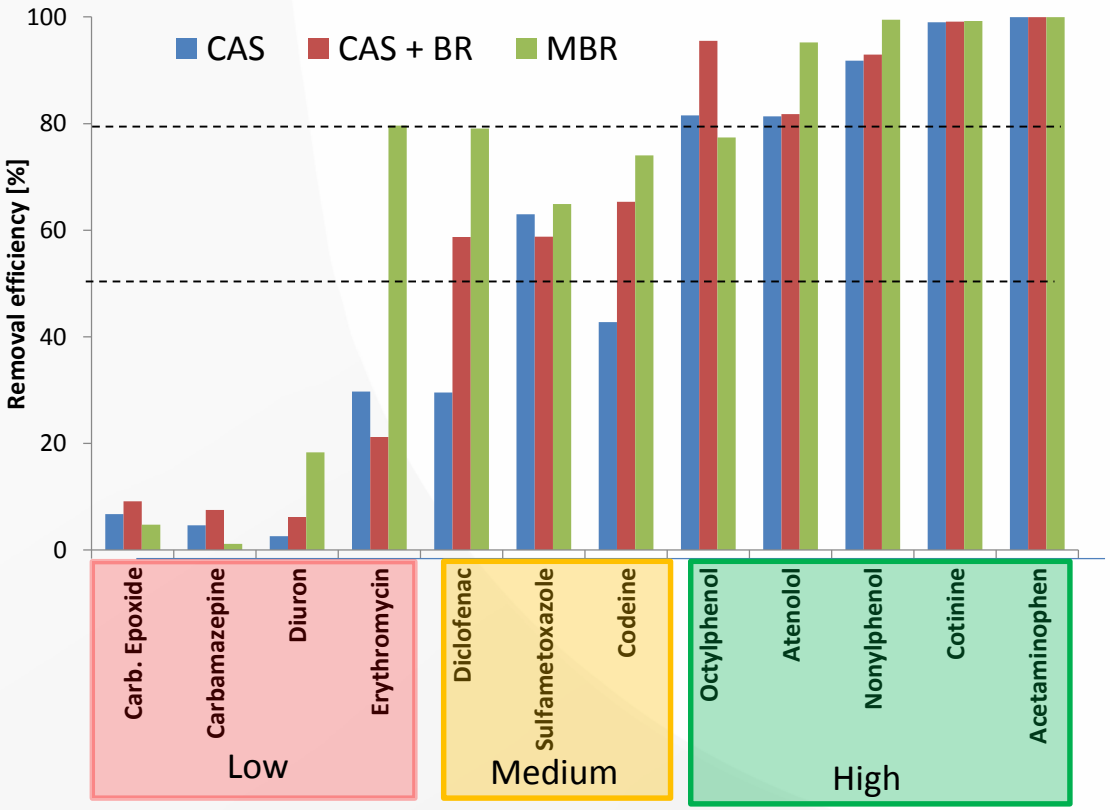
Parameter (Unit)	NF	PAC-NF	Advanced WRP-UF+RO
COD (mg-O_2/L)	15- 20	14 - 19	11 -18
BOD_5 (mg-O_2/L)	<1- 1.3	<1- 1.1	<1- 2
TOC (mg-C/L)	5.0- 6.0	4.5- 5.6	4.5- 7.2
TN (mg-N/L)	10.2- 13.6	9.9- 13.5	4.4- 6.6
NO_3^- (mg-NO_3/L)	44- 52	40 -50	4.2- 9.4
TP	0.3-1.5	0.3-1.5	0.3-1.1
SS (mg/L)	<1	<1	<1
Turbidity (NTU)	0.24- 0.47	0.28- 0.45	0.2- 1
E.Coli (CFU/100 mL)	<1	<1	<1
Legionella (UFC/L)	<100	<100	<100

PAC had no major influence on removal of organic matter or turbidity and the MBR showed similar performance to the Basic WRP

PAC had no major influence water quality and the NF presented similar performance to the advanced reclamation in terms of organics and turbidity

Results on the removal of priority and emerging pollutants

Conventional Activated Sludge (CAS) + Basic Water reclamation (BR)
Membrane bioreactor (MBR)



- **Basic reclamation contributes marginally to removal of PP and CEC:**
  - DIC : + 30 %)
  - COD : + 20 %
  - OCT :14 %
- **MBR and CAS + BR present similar performance Higher removls in the MBR for:**
  - ERY : (+50 %) ,
  - DIC :(+ 20 %),
  - ATE : (+13 %) ,
  - COD: (+ 9%)
- **Persitents organic micropollutants:**
  - Low removal :C.EPOX, CAR, DIU, ERY
  - Medium removal: DIC, SMX, COD

Results on the removal of priority and emerging pollutants

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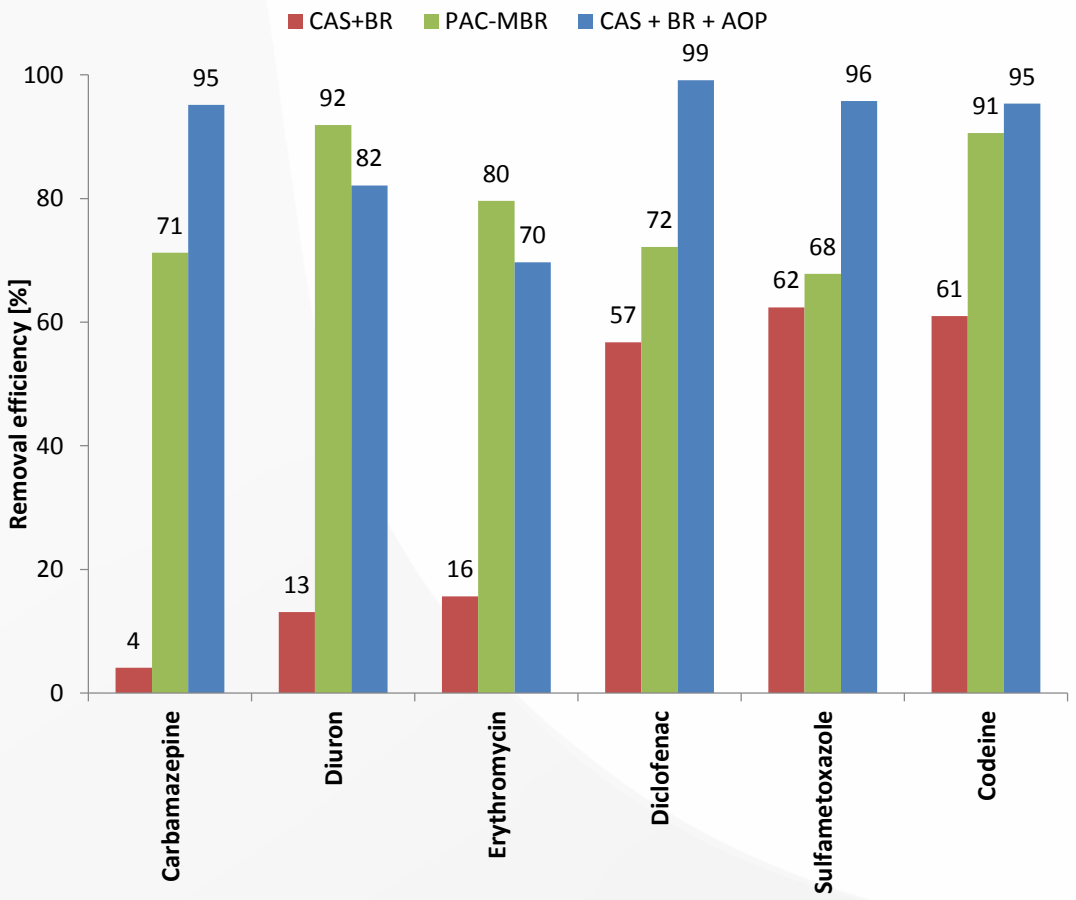
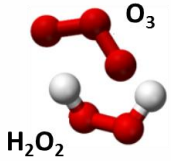
Removal of persistent PP and CEC with PAC and AOP (O_3+ UV)



Basic WRP + AOP | **MBR + PAC**



- **PAC addition (25 mg/L) enabled to médium-high removals (61-92 %)** for all **persitant** PP and CEC including **:**
  - **COD** that showed médium removal without PAC (74 %) increased the removal to 91 %.
  - **CAR and DIU** that were removed below 20 % in the MBR without PAC **improved the removal in the PAC- MBR to 71-92 %.**
- **UV + O_3 (400 J/m^2 + 6 mg/L)** also resutled in médium to high removals (70-95 %) for all persistent PP and CEC:
  - COD, SMX and DIC (57-62 % without AOP) **increased thier removal with AOPs to 95-99 %.**
  - **CAR, DIU, ERY (4-16 %) without AOPs increased their removal to 70-95 %**

Results on the removal of priority and emerging pollutants

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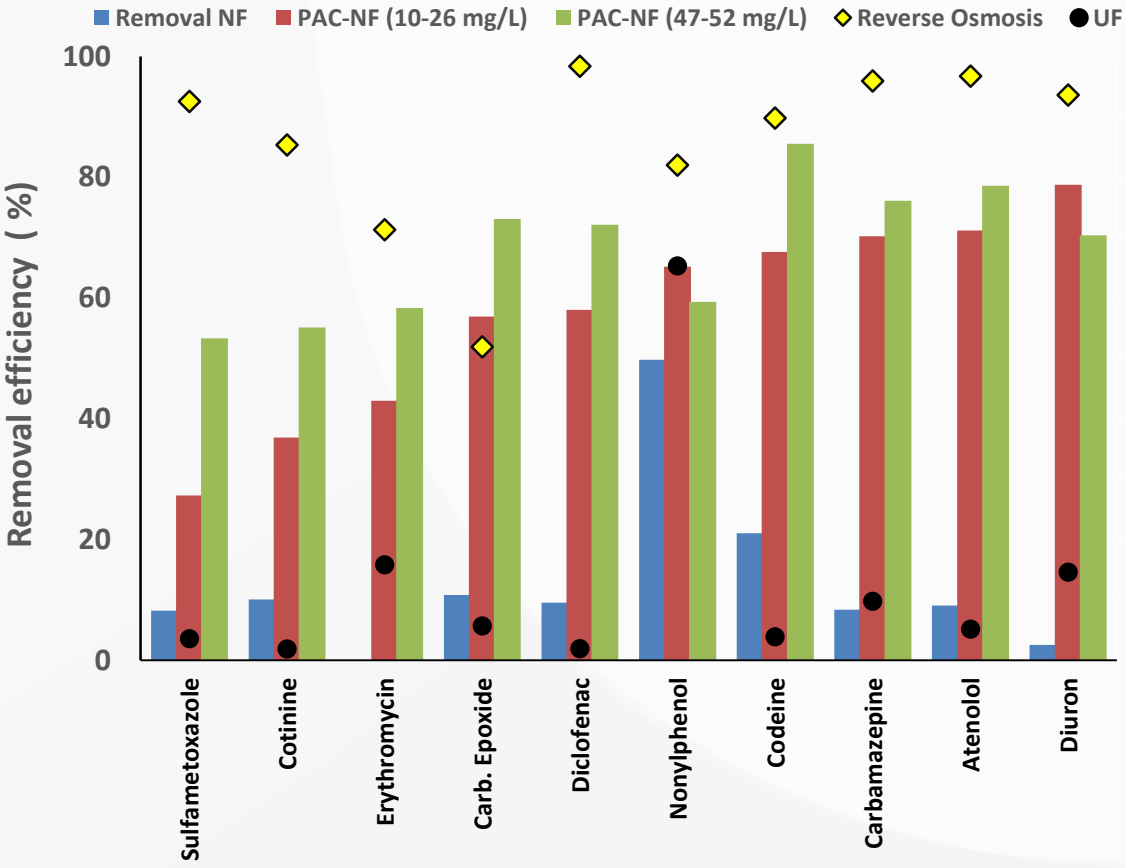
PAC/ NF and Advanced Reclamation UF/ RO



PAC-NF | **UF-RO**

- In the **RO** effluent all the organic micropollutants below LD: **Removals 81-98 %.**
- **Low contribution of NF** and **UF (< 20 %)** to removal of PP and CEC (200-300 Da).
- **PAC** addition **provided low –médium removal for the lowest dose of 10-25 mg/L** (27-79 %).
- **Increasing PAC dose to 47-52 mg/L** resulted in medium removal for most of the PP and CEC (53-86 %) with a maximum **increase of removal of 26 %** in comparsion to lower doses.

Technical, economic and environmental assesment

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Membrane bioreactor and Basic reclamation

Projections	MBR	CAS + WRP
Produced Flow (m^3/d)	330000	
Footprint (m^2)	60500	113 000
Sludge production (g SS/ g COD removed) [L WAS /g COD removed]	0,18 [6,4]	0,2 [12,5]
Total reagents needed (Tn/year)	5400	4400
Electricity consumption (kWh/m^3 treated eff.)	0,68 water 0,78 total	0,41 water 0,55 total

PAC-NF and Advanced Reclamation

Projections	PAC-NF	Advanced Reclamation
Produced Flow (m^3/d)	15000	
Footprint (m^2)	~2000	~2000
Overall Water Yield (%)	71,4	76,5
Brine Generation (m^3/d)	6000 (head works)	4471 (UF+ RO) (marine disposal)
Membrane area installed (m^2)	33 600 (1 stage NF)	48408
Electricity consumption (kWh/m^3)	0,35	0,70
Total reagents needed (Tn/year)	191	103

Comparison of MBR vs basic WRP

- 50 % reduction in footprint for MBR
- Similar sludge production in solid basis, 50 % reduction in volumen basis
- MBR effluent can be used as RO feedwater, basic WRP requires further UF step
- 20 % higher chemicals required due to membrane cleaning
- 40 % increase in over energy demands mainly due to membrane operation

Comparison of PAC-NF vs Advanced WRP

- 50 % reduction in energy demands
- 30 % reduction in membrane area installed
- Similar water yield compared to UF-RO (50:50 blend) , concentrate can be recycled to biological step
- 85 % increase in chemicals usage due to PAC dosing
- No salinity reduction or removal of nutrients but significant reduction in organic matter content

Implications for water reclamation treatment schemes

LCC and LCA evaluation on MBR , PAC-NF, Basic WRP and Advanced WRP

Basic water reclamation quality with removal of PP and CEC				
Scheme nº	% Removal (CAR, DIU)	% Removal (DIC, SMX, COD)	Cost difference with Basic WRP	Environmental Footprint (Kg CO_2/m^3 relcaimed WW)
Basic WRP	12	60	-	0.21
MBR	15	70	+ 31 %	0.28 (+ 33 %)
Basic WRP + AOP	80	95	+ 19 %	0.28 (+33 %)
PAC-MBR	80	75	+ 60 %	0.54 (+133 %)

Advanced water Reclamation quality with removal of PP and CEC (50 % RO)				
RO pretreatment	% Removal (CAR, DIU)	% Removal (DIC, SMX,COD)	Cost diference with Basic WRP + UF-RO	Environmental Footprint (Kg CO_2/m^3 relcaimed WW)
Basic WRP + UF	60	80	-	0.63
Basic WRP + AOP + UF	90	100	+ 7 %	0.70 (+ 9%)
PAC-UF-RO (Based on NF)	80	90	+11 %	0.89 (+ 40 %)
PAC-MBR	90	95	0 %	0.74 (+17 %)

Conclusions

If removal enhanced of PP and CEC is required, adding additional barriers is feasible and sustainable?

- For basic WRP (environmental, agricultural reuse without salinity reduction) , the application of AOP represents removal of 80-95 % PP and CEC which are persistent to conventional treatment with less than 20 % additional overall costs in comparison with conventional treatments

- For advanced WRP (aquifer recharge or agricultural reuse with partial reduction in salinity) the PAC-MBR as pretreatment of RO , enables 90-95 % removal of PP and CEC which are persistent to conventional treatment with comparable overall cost.

Acknowledgements

THANK YOU!

Nacho Martin Garcia, PhD

Project manager
imartin@cetaqua.com

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