Environmental assessment of an EBPR-SBR devoted to small populations

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UNIVERSIDAD DE CÁDIZ

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Content:

1. Institutional profile
2. Introduction and objectives
3. Material & Methods
4. Main results

1. Institutional profile

- **Foundation CENTA**
  - ✓ Research institute focused on WATER (mainly, wastewater treatment and water management)
  - ✓ Experimental Plant of Carrión de los Céspedes (Seville, Spain)
  - ✓ Technology and knowledge transference (Morocco, Latin-American, Palestine). Society awareness.

- **Department of Environmental Technologies (UCA)**
  - ✓ Advanced technologies for water treatment (membranes, AOP processes).
  - ✓ Biological aerobic/anaerobic treatment of wastewater and organic solid waste treatments.
  - ✓ Algae process for wastewater treatment.
  - ✓ Treatment of contaminated soils.
  - ✓ Environmental quality evaluation.

1. Institutional profile

Álvaro Real

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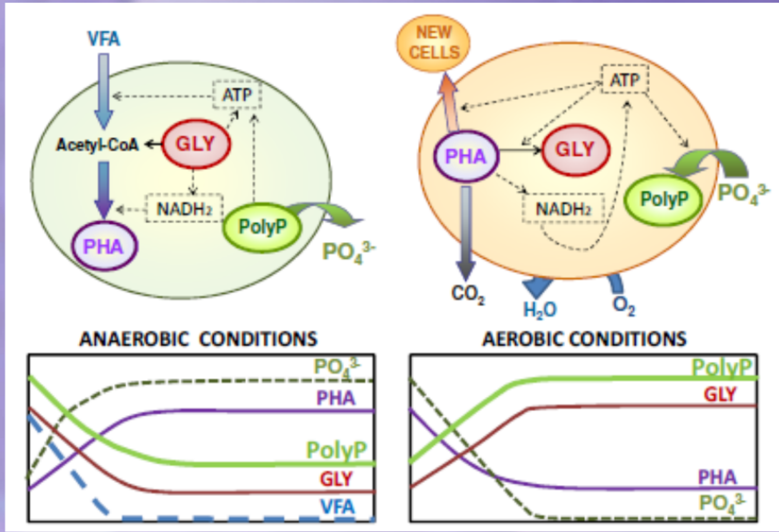
Content:

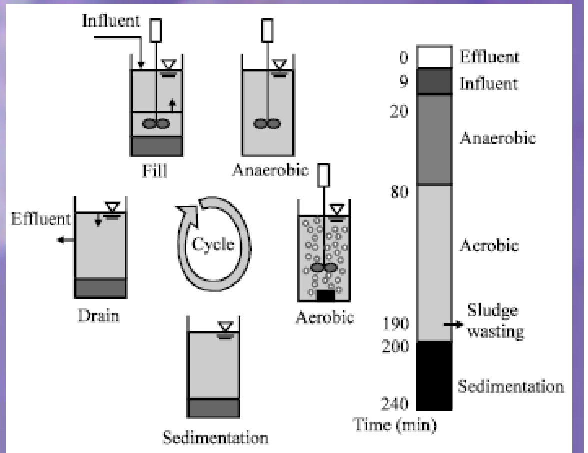
- **Reasons for removing nutrients from wastewater streams:**
    - ✓ Avoidance of eutrophication phenomena in lakes, rivers and other water bodies.
    - ✓ Discharge of treated water in sensitive areas (according to the EEC/91/271 Directive).
    - ✓ Restrictions to reclaimed water reuse in specific purposes.
    - ✓ Recovery of valuable nutrients for its further reuse.

Parameter	Concentration	Min. Removal rate(%)
Total phosphorous ($P\text{-}PO_4 + P_{organic}$)	2 mg P/l (10.000 - 100.000 p-e)	80
	1 mg P/l (>100.000 p-e)	
Total nitrogen ($NTK+N\text{-}NO_3$)$_{(2)}$	15 mg N/l (10.000 - 100.000 p-e)	70-80
	10 mg N/l (> 100.000 h-e)$_{(3)}$	

- Phosphorous removal:
  - Chemical precipitation → largely employed
  - Enhanced biological P removal-EBPR: combination of anaeorbic-anoxic and aerobic conditions for the promotion of PAO (Baetens *et al.*, 2001).



- **EBPR in Sequencing batch reactors (SBR).**
  - ✓ In each SBR cycle, phosphorus is released during an initial anaerobic period. Subsequently, the reactor is aerated and phosphorus is taken up by PAOs. This results in a net uptake of P over the cycle.
  - ✓ Simultaneous nitrogen and phosphorus removal process. Promotion of denitrifying phosphate-accumulating organisms (DNPAOs) in the SBR.
  - ✓ SBR benefits: easy to change operating conditions, such as cycle times and flow rates → flexible system for promoting PAOs in the activated sludge.



2. Introduction & objectives

- WWTP help us to protect the environment, but in contrast, they can **damage the environment** through energy consumption, greenhouse gas emission, the released of nutrients (mainly N and P), the utilization of chemicals, and some toxic material outcomes (Buyukkamaci, J., 2013).

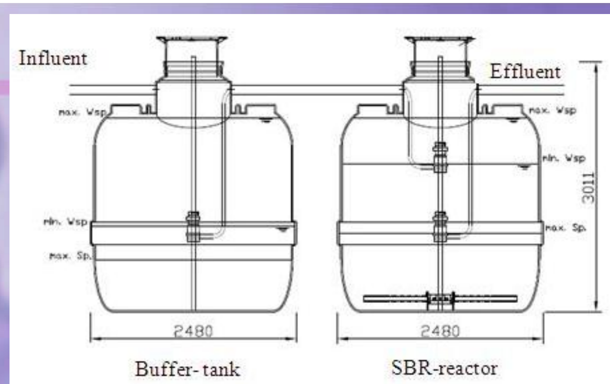
- In the last two decades a number of methodologies have been developed for evaluating the environmental sustainability of a product or process. Among them, Life Cycle Assessment (LCA) is a well-established procedure quantifying inputs and outputs as well as the potential environmental impacts associated with a product throughout its whole life cycle (Finnveden et al., 2009). LCA has been satisfactorily applied to water treatment systems (Larsen et al., 2007).

The aim of this research paper is to environmentally assess the operation of an EBPR-SBR reactor devoted to small decentralized populations (45 p.e.) and compare it with a conventional activated sludge system.

Content:

3. Material & Methods

- SBR-45 p.e.:
  - ✓ Three cycles per day (8 hours-length).
  - ✓ Sequence of a first aerobic phase (60 min) followed by an anaerobic/anoxic phase (250 min) and a final full aeration phase (90 min).
  - ✓ Aeration pattern with a double objective: promote the presence of PAO and, save energy.
  - ✓ Flow rate ~ 9-10 m^3/day, HRT ~0.66 days and sludge age ~20 days.



- Conventional activated sludge (CAS)

  - ✓ Flow rate ~ 30 m^3/day , HRT ~ 14 h and sludge age ~15 days.
  - ✓ Anaerobic pond as primary treatment, biological reactor (17.8 m^3) divided in two compartments: anoxic tank (1/3 approx.) and aeration tank (2/3 approx.) followed by a secondary settler.
  - ✓ Nitrification- denitrification

- **Environmental assessment:** Two different functional units (FU), one based on volume (m^3) and the other on eutrophication reduction (kg PO_4^{3-} removed).
  - *Global Warming Potential (GWP)* to weight the greenhouse effect.
  - ✓ The GWP of a greenhouse gas gives the ratio of time-integrated radiative forcing from the instantaneous release of 1 kg of a trace substance relative to that of 1 kg of a reference gas (IPCC 2001). Thus, the GWP is a relative measure used to compare the radiative effects of different gases.
  - ✓ The GWP of a GHG is the ratio of heat trapped by one unit mass of the gas compared to one unit mass of CO_2 over a certain time period, usually 100 years.

The GWP, radiative forcing, residence time, and atmospheric concentrations of GHGs produced in the WWTPs (Wallington et al., 2004)

GHG	Radiative Forcing (W/m^2)	GWP over 100-year period	Atmosphere residence time (years)	Atmospheric concentration (ppb)
CO_2	0.000018	1	5-200*	370000
CH_4	0.00037	23	12	1750
N_20	0.0032	296	114	314

*No single life time can be allotted to CO_2 because of different rates of uptake by different removal processes.

GHGs emissions in SBR and CAS

	CO_2	CH_4	N_2O
CAS	168 g/m^3 (Monteith et al., 2005)	3.3 g/m^3 (Daelman et al., 2013)	1.6 g/m^3 (Daelman et al., 2013)

Environmental assessment: continuation.

- *Eutrophication potential (EP)*

✓ Impact due to the remaining nutrients in the effluent has been considered the most relevant environmental issue when performing environmental evaluation of WWTPs (Garrido-Baserba et al., 2014).

✓ The EP is expressed in equivalent mass units of phosphorous released. In the present study, the EP has been estimated through the concentration of nitrogen and phosphorus in the effluent along the test period.

Equivalent EP factors (g eq. PO_4^{3-}) (TEAM, 1999)

Substance	EP
NH_3	0.35
NH_4^+	0.42
NO_2	0.13
COD	0.022
PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, H_3PO_4	3.06
P	3.06
NO_3^-	0.095
NO_2^-	0.13

- *Power consumption (kWh/kg PO_4^{3-} $_{removed}$)*

Content:

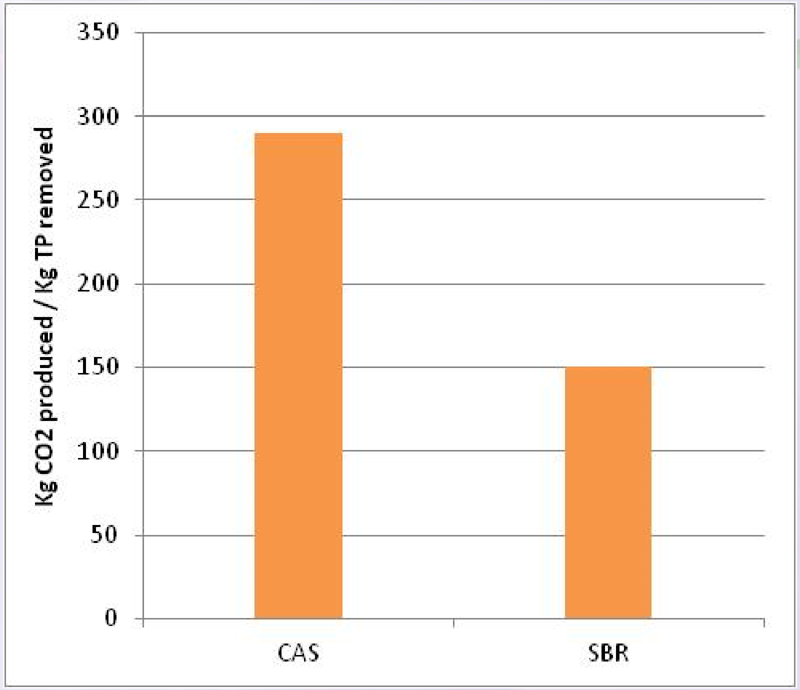
SBR and CAS performance

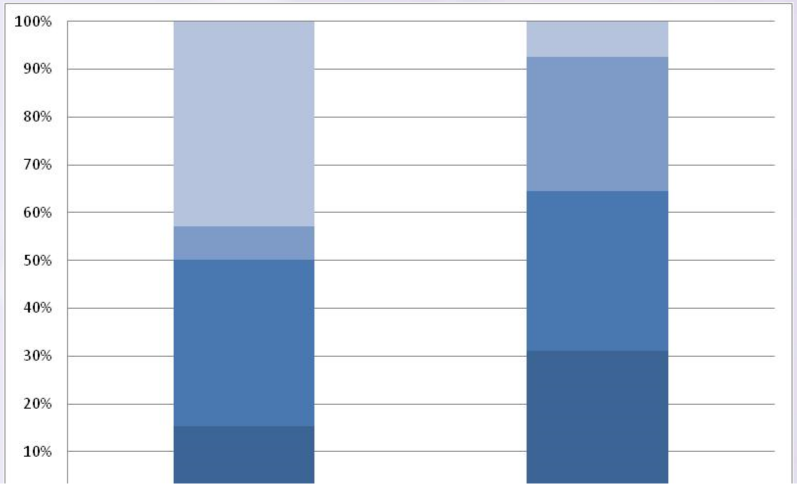
Parameter	SBR		CAS	
	Effluent	%	Effluent	%
SS (mg/l)	9.3 ± 4.5	91	30.1 ± 10.4	84
COD (mg/l)	39.6 ± 13.5	90	75.2 ± 16.7	80
BOD_5 (mg/l)	6.9 ± 2.6	97	25.4 ± 8.3	90
TN (mg N/l)	15.8 ± 6.3	77	33.2 ± 14.4	32
$N\text{-}NH_4$ (mg N/l)	7 ± 7.4	91	18.3 ± 19.2	25
$N\text{-}NO_3$ (mg N/l)	5 ± 2.8	-	10.8 ± 12.5	-
TP (mg P/l)	0.5 ± 0.6	93	3.9 ± 2.6	45
$P\text{-}PO_4$ (mg P/l)	0.4 ± 0.6	94	2.1 ± 1.7	48

- ✓ SBR: all the removal rates exceeded 90%, except the TN. According to these results, the effluent of the EBPR-SBR met the requirements imposed by the 91/271/EEC Directive for sensitive areas. The energy consumption during the assay was 10 kWh/day.
- ✓ CAS: good performances in terms of SS and organic matter removal but the nitrification-denitrification processes were limited (due to electromechanical failures). P removal rate ~ 45%. The presence of PAO and the direct precipitation of phosphorous salts could explain this unexpected rates. The energy consumption reached 40 kWh/day.

GWP

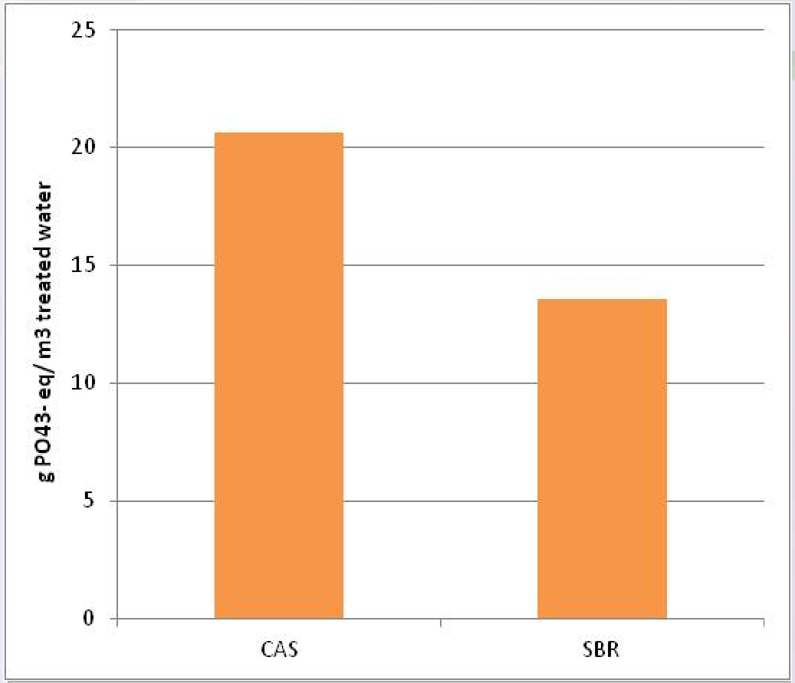
- GWP is expressed in terms of kg CO_2/ kg PO_4^{3-} $_{removed}$ taking into account the flow-rate and P load on both systems.
- CO_2 production/kg$P_{removed}$ in CAS doubled the one obtained for the SBR → higher performance of the SBR in terms of P removal and, also, the lower energy consumption registered in that system.
- Weighted-sources of CO_2:
  - SBR: 1/3 due to the oxidation of the organic matter; 1/3, to the energy consumption; and 1/3, due to the emission of CH_4 and N_2O.
  - CAS: the eq CO_2 due to N_2O emissions represented a large percentage (expla.: incomplete nitri-denitrification, Daelman et al., 2013). Second source of CO_2, the



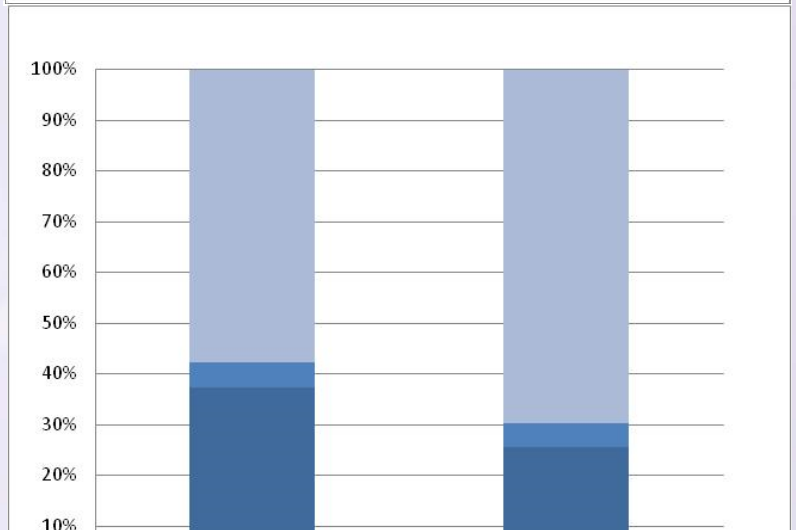


EP

- Larger performances in terms of nutrients removal observed in SBR led to a lower EP in comparison with the CAS.



- In both cases, the largest EP was related to the emission of PT in the effluent meanwhile the EP due to NH_4 and NO_3 emissions represented approximately 40% in the CAS and 30% in the SBR.



Power consumption (PW) related to P removal

- ✓ The PC in SBR reached 175 kWh/ kg $PO_4^{3-}$$_{removed}$, meanwhile in the CAS it increased up to 350 kWh/ kg $PO_4^{3-}$$_{removed}$.

According to the results of this study, an optimised operation of an EBPR-SBR, involving a energy-saving aeration pattern, allows, on one hand, the fulfilment of the Directive 91/271/CEE and, on the other hand, the reduction of its environmental impact in terms of GWP, EP and PC if compared to a conventional activated sludge system.

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