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Experiences on nitrogen removal from liquid fraction of pig slurry using the SBR technology

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An overview on the use of the SBR technology for N-removal from liquid fraction of pig slurry by means of nitrification-denitrification is presented. Laboratory-, pilot- and full-scale experiences have been collected and typified. The composition of piggery wastewaters may vary widely depending on factors such as geographical area, management, pre-treatments, etc., circumstances that affect the operation and performance of a SBR system. The compiled experiences showed that SBR is a flexible and mature technology to properly deal with nitrogen removal under very different situations.

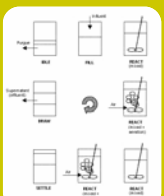
Keywords: Nitrification-denitrification (NDN); Sequencing batch reactor (SBR); Piggery wastewaters; Nitrogen surplus

Nitrogen surplus derived from intensive pig farming

Slatted floors in farming has led to the production of livestock slurries with low dry matter contents. The use of these slurries as organic fertilizer is the most adequate option but when slurry generation is larger than crop needs a problem of nutrient surplus appears. Under these circumstances, complementary treatment strategies have to be considered. Up to 50-60% of the total nitrogen initially present in a pig slurry is susceptible of being biologically eliminated through NDN.

Sequencing Batch Reactor technology

A conventional SBR consist on an activated sludge system operated with a fill and draw sequence (cycle), which is repeated over time



Raw Liquid Fraction of Pig Slurry (LFPS)

- **High compositional variability** within regions, farms or seasons and also due to the separation device used
- **TS content 0.5-2.5%**
- **Variable BOD/COD ratio.** BOD mainly attributed to **slowly biodegradable organic compounds**
- **High N concentration is expected** in both, ammonium and organic forms, although NH_4^+-N is dominant (~70%).
- **Presence of other nutrients** (P and K), certain heavy metals (Cu and Zn) and other ionic species which confers a **significant electric conductivity**
- Presence of **pathogens**

LAB-SCALE

Reference	LFPS	External Org.	Operation					Influent (g l^{-1})			Removal (%)		
		C supply	NLR (g l^{-1} d^{-1})	HRT (d)	SRT (d)	CL (h)	Cycle (h)	Org. C	N	P	Org. C	N	P
Wun-Jern (1987)	R+D/AD	No	0.27-0.44 NH_4-N	1.3	∞	24	3_16_1_0.5_3.5 OF_OR_S_D_AI	2.19-2.79 COD	0.35-0.56 NH_4-N	-	48-58 COD	66-2 NH_4-N	-
Fernandes and McKyes (1991)	R	No	0.13-0.40 NH_4-N	3-9	10-30	24	3_19_1_0.5_0.5 AF_OR_S_D_AI	25.0-32.0 COD	1.00-1.40 NH_4-N	-	81-97 COD	<35-84 NH_4-N	-
Fernandes *et al.* (1991)	R	No	0.14-0.20 TKN	6-9	20	24	3_9-18_0-9_1_1_0.5_0.5 AF_OR_AR_OR_S_D_AI	30.7-31.2 COD	2.41-2.58 TKN	-	95-97 COD	80-93 TKN	-
Osada *et al.* (1991)	R+D	No	0.09-0.22 TKN	3	17-19	24	0.5_[1_1]^{10}_1_2_0.5 AF_[OR_AR]^{n}_AR_S_D	1.50-2.25 BOD_5	0.28-0.67 TKN	0.08-0.24 TP	91-96 BOD_5	72-98 TKN	19-91 TP
Bortone *et al.* (1992)	R	No	0.13 TKN	10	28-34	24	6_7_4_6_0.8_0.2 [AiFR_OR]^{2}_S_D	10.6 COD	1.26 TKN	0.24 TP	93 COD	88-93 TKN	95 TP
Maekawa *et al.* (1995)	R+P	No	0.98 TKN	1.2	-	24	[1_1]^{12} AiF_[OR_S]^{n}_iD	8.20 BOD	1.17 TKN	0.11 TP	~90 Org. C	91 TKN	-
Andreottola *et al.* (1997)	R	No	0.21 TKN	10	30	24	[3.3_4.2]^{3}_1.5 [AiFR_OR]^{n}_S+D	19.1 COD	2.06 TKN	-	-	98 NH_4-N	-
Lee *et al.* (1997)	R+D	Yes	0.07 TKN	2	19	24	0.2_13_7_3_0.6_0.2 AF_OR_ARe_OR_S_D	2.85 COD	0.15 TKN	0.05 TP	96 COD	90 TKN	89 TP
Magrí and Flotats (2000)	R	No	0.13 TKN	21	20	24	6_8_5_4_0.8_0.2 [AiFR_OR]^{2}_S_D+AI	18.7 COD	2.67 TKN	1.05 TP	98 COD	99 TKN	-
Kishida *et al.* (2003)	R+C	No/Yes	0.11-0.13 TKN	10	46-560	8	3.3_4_0.6_0.1 AiFR_OR_S_D	2.96-5.62 BOD_5	1.13-1.25 TKN	-	98-~100 BOD_5	51-96 TKN	-
Obaja *et al.* (2003)	AD+D	Yes	0.91-1.65 NH_4-N	1	11	8	2_4_1_1 AiFR_OR_ARe_S+D	2.26-3.97 COD	0.91-1.65 NH_4-N	0.09-0.15 PO_4-P	64-70 COD	~100-97 NH_4-N	95-98 PO_4-P
Chen *et al.* (2004)	R+C	No/Yes	~0.11-0.07 TKN	~6.3-10	-	Variable	0.1_Var_Var_0.9_0.1 AiF_ARø/e_OR_S_D	2.91 BOD_5	0.71 TKN	0.05 TP	98-~100 BOD_5	61-96 TKN	16-56 TP
Kim *et al.* (2004a)	pAD	No	0.11-0.22 TKN	20-40	-	-	7-16.5_4.5-12_1-3_2 AFR_OR_AR_S+D+AI	19.5-48.8 COD	4.34-4.82 TKN	-	92-97 COD	95-97 TKN	-
Kim *et al.* (2004b)	R+C	Control strategy	~0.10-0.08 TKN, Variable	~7.5-9 Variable	32	~3.3-4.0 Variable	0.1_Var_Var_0.9_0.1 AiF_ARe_OR_S_D	3.21 BOD_5	0.72 TKN	0.05 TP	~100 BOD_5	96 TKN	50 TP
Obaja *et al.* (2005)	AD+D	Yes	1.03 NH_4-N	0.9	11	7	1_2_1_[0.5_0.5]^{3} AiFR_[OR_ARe]$^{1+n}$_iD	1.74 COD	0.90 NH_4-N	0.08 PO_4-P		~100 TKN	98 PO_4-P
Deng *et al.* (2006)	pAD	No	0.26 TKN	3	30	12	3_3_3_1_1_1 OR_AR_OR_AF_S_D	2.81 COD	0.79 TKN	-	90 COD	93 TKN	-
Zhu *et al.* (2006)	R+D	No/Yes	0.37 TKN	3.3	21	8	1.25_2.75_1.5_2_0.5 AF_OR_AiFR_S+D	8.80 COD	1.22 TKN	0.60 TP	98-97 COD	96-99 TKN	68-87 TP

LARGE-SCALE

Reference	LFPS	External Org.	Operation					Influent (g l^{-1})			Removal (%)		
		C supply	NLR (g l^{-1} d^{-1})	HRT (d)	SRT (d)	CL (h)	Cycle (h)	Org. C	N	P	Org. C	N	P
Wong and Choi (1989)	R	No	0.08 TKN	9	9-12	24	3_18_1_2 AFR_OR_S_D	2.88 BOD	0.70 TKN	-	>99 BOD	-	-
Lo *et al.* (1991)	R+D	No	0.34 NH_4-N	1	14	4	0.1_3.3_0.5_0.1 OF_OR_S_D	2.35 COD	0.33 TKN	-	52 COD	0 TKN	-
Su *et al.* (1997)	R	No	0.09 TKN	3	-	24	0.5_[3.5_2]^{4}_0.5_1 AF_[OR_S]^{n}_D_AI	3.77 COD	0.28 TKN	0.26 TP	89 COD	36-53 TKN	61 TP
Bicudo *et al.* (1999)	R	No	0.13-0.24 TKN	5-10	30-35	12-24	[1_1], [4_4-6], [2_2] [AR_OR]	3.60-8.20 COD	1.10-1.30 TKN	0.15-0.20 TP	65-93 COD	75-95 TKN	15-70 TP
Su *et al.* (1999)	pAD	No	-	3	-	24	0.75_[3.5_2]^{4}_1.25 F_[OR_S]^{n}_D+AI	0.42 COD	-	-	44 COD	47-65 TKN	-
Tilche *et al.* (1999)	R	No	0.12 TKN	5.7	15	24	[2_2]^{5}_1.5_2.5 [AFR_OR]^{n}_S_D+AI	6.46 COD	0.70 TKN	0.09 TP	98 COD	98 TKN	98 TP
Edgerton *et al.* (2000)	R	No	0.08 NH_4-N	6.7	30	9.5	0.25_2_3.5_2.5_1_0.25 AF_AR_OR_AR_S_D	4.50 COD	0.55 NH_4-N	0.06 PO_4-P	79 COD	~100 NH_4-N	49 PO_4-P
Choi and Eum (2002)	R	No	0.10-0.20 TKN	54	54	24	8_16 AFR_OR	45.3 COD	6.68 TKN	0.67 TP	-	(30+50) TKN	-
Poo *et al.* (2004)	R/AD	Yes	0.35-0.22 TKN	10-25	-	24	[1_3]$^{4+1}$_3_1 [AiFR_OR]^{n}_S_D+AI	47.5-11.0 COD	4.75-3.70 NH_4-N	0.10-0.03 PO_4-P	-	99-98 TKN	-
Poo *et al.* (2005)	R	Yes	0.14-0.43 NH_4-N	27-9 Variable	-	Variable	[1_Var]$^{4+1}$ [AiFR_OR]^{n}_S_D+AI	11.0 COD	3.80 NH_4-N	0.02 TP	-	~100 NH_4-N	-

Nomenclature. NLR: nitrogen loading rate; HRT: hydraulic residence time; SRT: solids residence time; CL: cycle length; F: fill; AF: anoxic fill; OF: oxic fill; AiF: anoxic instantaneously fill; AFR: anoxic/anaerobic fill and react; AiFR: anoxic/anaerobic instantaneously fill and react; OFR: oxic fill and react; AR: anoxic/anaerobic react; ARe: anoxic/anaerobic react with external carbon addition; OR: oxic react, S: settle; D: draw; iD: instantaneously draw; AI: anoxic/anerobic idle; n: times that a sequence is repeated; Var: Variable. ***LFPS characteristics.*** R: raw; D: diluted; AD: anaerobically digested; pAD: partially anaerobically digested; P: precipitated; C: coagulated. ***N removal.*** Also including N oxidized forms, over liquid effluent.

"Hot" issues

Nitrification

- High electric energy consumption linked to aeration
  - ❖ 4.57 kg O_2 kg^{-1} NH_4^+-N on stoichiometric basis
  - ❖ 11.3 kWh m^{-3} slurry, overall treatment plant (Tilche *et al.*, 1999)

Denitrification

- Organic carbon requirements (~6 kg BOD kg^{-1} $N_{nitrifiable}$)
  - ❖ High BOD favors aerobic heterotrophic growth, increasing O_2 consumption and may even destabilize the process due to the temperate rise (>35ºC). Advisable to consider a preliminary anaerobic digestion
  - ❖ Low BOD limits denitification. Proposed alternatives:
    - addition of an external carbon source (in this context NDN via nitrite may result interesting)
    - partial separation of NH_4^+-N by struvite precipitation

Control performance

- Timers *vs.* real-time probe measurements
- Minimization of greenhouse gasses emission (NO_2, CH_4)

Engineering

- Based on previous laboratory assays/simulation
- Possibility of upgrading outdated installations

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New biotechnological developments on N-removal that are more energy efficient, such as the PANI-Anammox, might replace treatment strategies based on NDN provided that robustness, flexibility and simplicity are ensured.

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