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BIOLOGICAL NUTRIENT REMOVAL IN A FULL SCALE SEQUENCING BATCH REACTOR TREATING PIG SLURRY[1]

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ABSTRACT

In Italy, pig farming is concentrated in few areas, mainly located in the Po valley and in the Umbria Region. The high concentration and the industrial typology of piggery farms, often not connected with land cultivation, lead to an excessive generation of animal slurry, frequently higher than their recycling potential on land as a fertiliser. One option to reduce manure surplus can be slurry treatment before spreading on land and/or for discharge into municipal sewer or surface waters. The last option was experienced in the past with rare success, due to both economic-management and to technical causes. Traditional nutrient removal processes, based on pre-denitrification configurations, do not allow to reach discharge standards for nitrogen.
A laboratory research using Sequencing Batch Reactors (SBRs), allowed to demonstrate the possibility to better drive the use of the carbon source towards biological nitrogen and phosphorus removal, through the correct design of the time cycle, in order to obtain low levels of nutrients in the final effluent.
The process has been modelled and the model was used for designing and building two full scale plants in two pig farms in Modena, Italy, with an average animal population of about 800 and 950 tons of live weight. The plants are composed of two parallel SBRs.
In the paper the results of about one year of monitoring of one of the two plants are reported.
The Sequencing Batch Reactor has been demonstrated to be an efficient biological process, capable to obtain very low nitrogen and phosphorus concentrations from pig slurry, with COD, nitrogen and phosphorus removals higher, respectively, than 98%, 98% and 96%. Running costs (energy, labour and maintenance included) are around 3 EURO/ m^3 of slurry treated.

1. INTRODUCTION

In Italy, pig farming is concentrated in few areas, mainly located in the Po valley and in the Umbria Region. The high concentration and the industrial typology of piggery farms, often not connected with land cultivation, lead to an excessive generation of animal slurry, frequently higher than their recycling potential on land as a fertiliser. One option to reduce manure surplus can be slurry treatment before spreading on land and/or for discharge into municipal sewer or surface waters. The last option was experienced in the past with rare success, due to both economic-management and to technical causes.
Traditional nutrient removal processes, based on pre-denitrification configurations, do not allow to reach discharge standards for nitrogen.
Research carried out at ENEA (Tilche et al., 1994) with an upgraded pilot scale (continuous flow) nutrient removal treatment plant treating piggery wastewater with initial average concentration of 27,000 mg/L COD, 1,550 mg/L TKN and 725 mg/L P_{tot} allowed to obtain removal efficiencies of 96% for COD and 92% for nitrogen and phosphorus, still resulting in concentrations far higher then discharge standards.

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Other laboratory research (Bortone et al., 1992; Bortone et al., 1994), using Sequencing Batch Reactors, allowed to demonstrate the possibility to better drive the use of the carbon source towards biological nitrogen and phosphorus removal, through the correct design of the time cycle, in order to obtain low levels of nutrients in the final effluent.
The process has been modelled (Andreottola et al., 1997) and the model was used for designing a full scale plant at the S.Anna farm in Magreta (Modena, Italy), a full cycle piggery with an animal population of about 800 tons of live weight, breeded on partially slotted floors, with an estimated slurry production of about 150-190 L/(d·ton of live weight). The plant, designed for a minimum wastewater temperature of 12°C, applying a safety factor of 1.5, resulted of a total working volume of 2,500 m^3, with a maximum daily need of 1,500 kg O_2 and a design sludge age of 15 days.
In the present paper the results of about one year of monitoring are reported.

2. MATERIALS AND METHODS

Plant description

The plant, schematically represented in fig.1, is composed of two parallel SBRs (25x10x5(H_{max})m each). The wastewater is collected into a mixing and pumping tank from where it is pumped into a Pieralisi FP600.2RS centrifuge working at a flow rate of about 12 m^3/h. The liquid fraction is sent to the equalisation tank, where it is mixed with other supernatants deriving from the sludge settling and dewatering. Submerged pumps load alternately the two Sequencing Batch Reactors at the beginning of each denitrification phase, during which only the mixer is operating. Each SBR is equipped also with two ABS 1200 TAK submerged aerators, each one of 35 kW power. The clarified effluent is discharged, by means of a submerged pump installed about 1 m below the minimum liquid level, into some storage lagoons. Excess sludge is withdrawn before the end of each oxidation phase and is transferred to a gravity settler. The supernatant returns to the equalisation tank, while the settled sludge is transferred to a gravity thickener. The thickened sludge is dosed to a second centrifuge (equal to the previous) after addition of cationic polyelectrolite; the thickener supernatant and the liquid fraction from the centrifuge return to the equalisation tank.

SBR cycle description

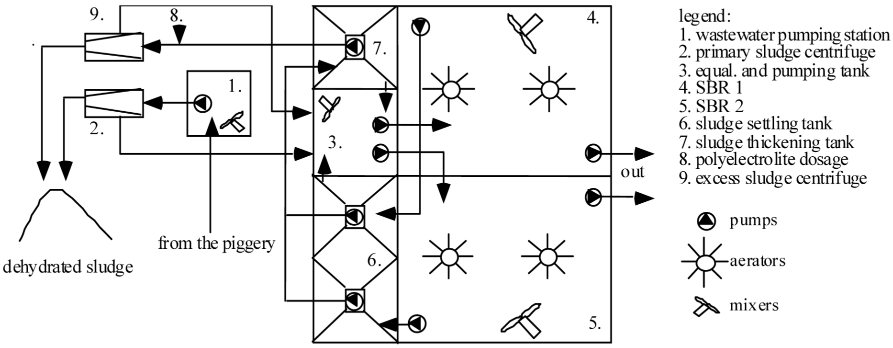
Each 24h period was divided into six four-hour modules, five reaction modules and one settling phase. Each reaction module was composed of 2h of anoxic-anaerobic conditions and 2h of oxic ones. The anoxic-anaerobic phase started with a 5 minutes mixing period without feed followed by about 1h (variable due to level control) anoxic feed. The oxic phase was characterised by the transfer to the settlers of a portion of the mixed liquor towards the end of the phase; this strategy was chosen to better manage the sludge age (fixed to about 20 d) respect to the option of extracting the settled sludge. In the final 4h settling phase, supernatant extraction started after 2h30' of settling and was level-controlled.

Sampling and analyses

Sampling was carried out for a period of twelve months, every two weeks. Each sampling consisted of a series of samples in various parts of the plant (raw influent, centrifuged solids, equalisation tank, mixed liquor, liquid effluent). For the characterisation of the

equalisation tank content, automatic sampling was carried out every 6 h for a period of one week using a refrigerated autosampler.
Analyses of samples were carried out according to the procedures described in Standard Methods (APHA, 1989).

Fig. 1: Schematic drawing of the full scale SBR plant



3. RESULTS AND DISCUSSION

Analyses of raw slurry gave highly dispersed results, as it can be seen from the high standard deviation of data presented in Tab. 1.
The first centrifuge allows to produce a solid fraction at about 27% TS that removes a variable fraction of total COD (35-50%), a similar fraction of total phosphorus and a slightly lower fraction of total nitrogen. The correct evaluation is quite difficult due to the high error in sampling. Primary sludge represents in term of weight about 6-7% of the influent. Tab. 2 reports an average flow balance of the plant.
The plant has been started up on September 1997, partially filling the SBR tanks with water and adding to each tank about 30 m^3 of activated sludge from a nearby treatment plant treating piggery wastewater. With a gradual increase of loading, the plant reached the full treatment capacity after about three weeks. Removal efficiencies are for the main parameters always higher than 98%. If efficiency is calculated for the sole biological process, values are only slightly lower.
Moreover, despite of the very low concentration of suspended solids, the presence of colloidal suspended material gives relatively high effluent values of COD and TKN. Laboratory Jar tests, dosing $FeCl_3$ as coagulant at 90 mg/L, allowed to remove more than 50% of the COD in the clarified effluent. A coagulant dosing station is however present in the full scale plant, but it was never put in operation, because the effluent concentrations were always well inside the required limits for agriculture use.
The average effluent values are much higher than the best values obtained during summer-fall 1998, because some winter 1998 samples gave considerably worse results (particularly for suspended solids, TKN, COD and BOD_5), probably due to some temporary overloading caused by a higher presence of animals in the farm.

Tab. 1. Main quality characteristics of influent, equalisation and effluent

Parameter	Unit	Raw influent			Equalisation tank			Final effluent			Removal %
		Average	s.d.	n.	average	s.d.	n.	average	s.d.	n.	average
TS	(g/kg)	18.62	6.62	18	5.96	0.93	17				
VS	(g/kg)	13.14	5.56	18	2.62	0.59	17				
	(%TS)	69.07	5.38		43.7	5.71					
TSS	(g/kg)	15.35	6.54	18	1.93	0.72	17	0.32	0.87	18	97.9
	(%TS)	80.83	10.86		31.72	9.35					
TKN	(mg/kg)	1963	452	18	681.2	139.5	17	29.1	22.7	18	98.5
	(%TS)	11.15	2.35		11.43	2.34					
$N-NH_4$	(mg/kg)	1264	293	18	522.3	119.2	17	6.4	12.4	18	99.5
	(%TKN)	64.79	14.93		76.67	17.50					
$N-NO_3-NO_2$	(mg/kg)						17	10.8	7.9	18	
COD	(mg/kg)	24792	9707	18	6016	1672	17	356	218	17	98.6
BOD_5	(mg/kg)							93	79	17	
$P_{tot.}$	(mg/kg)	547	155	18	91	38	17	22	10	17	96.0
Cu	(mg/kg)	7.74	4.54	18				0.00	0.00	2	100.0
Zn	(mg/kg)	25.72	10.97	18				0.36	0.06	2	98.6

Tab. 2: Average flow balance

Parameter	Unit	Av. value
Influent flow to 1st centrifuge	m^3/d	150
1st centrifuge solids	m^3/d	9*
SBR feed flow	m^3/d	315
Mixed liquor extraction to settlers	m^3/d	174
Sludge flow to thickener	m^3/d	80
Thickened sludge flow to 2nd centrifuge	m^3/d	60
2nd centrifuge solids	m^3/d	5**
Final effluent flow	m^3/d	139-165

* density 0.9; TS 270 kg m^{-3}; ** TS 170 kg km^{-3}

4. CONCLUSIONS

The Sequencing Batch Reactor has been demonstrated to be an extremely efficient biological process, capable to obtain very low nitrogen and phosphorus concentrations from highly concentrated wastewaters - like piggery wastewater - with COD, nitrogen and phosphorus removals higher than 96%. A proper design of the time cycle is therefore necessary, and modelling capacity is needed to optimise the duration of the single phases. The proposed process, implemented in full scale, can represent a new chance for solving environmental problems generated by large industrial piggeries, when other more "sustainable" options cannot be adopted in the short term. Running costs (energy, labour and maintenance included) are around 3 Euro/m^3 of slurry treated.

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