

MODELLING OF BIOLOGICAL PROCESSES DURING AEROBIC TREATMENT OF PIGGERY WASTEWATER AIMING AT PROCESS OPTIMISATION

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ABSTRACT

For the optimisation of the biological intermittent aeration treatment of piggery wastewater, biological processes were investigated using 100L pilot-plant. The results demonstrated that more than 60% of total nitrogen was removed in gaseous form by nitrification followed by denitrification during the anoxic phase. During nitrification, oxidation of ammonium to nitrite was slower than oxidation of nitrite to nitrate leading to nitrite accumulation during aeration phase. Finally, a mathematical model was developed from experimental results to obtain process optimisation and used to predict the characteristics of the treated slurry.

Keywords: *piggery wastewater; nitrogen removal, nitrification, denitrification, modelling, optimisation.*

INTRODUCTION

In France, the concentration of pig farming in Brittany is mostly based on liquid waste management systems, lead to an excessive production of wastes by the piggery farms which is frequently higher than the capacity to recycle to the land as fertiliser. Restrictions on landspreading from regulations by national and European legislators for the protection of water from nitrate pollution (91/676/EEC Directive), has lead to a reduction of the amount of nitrogen applied to land. This is especially so in areas of high animal density and nitrate vulnerable zones. To meet these regulations, different options are possible: move pig farms from these vulnerable zones, modify buildings structure to produce solid wastes and then export wastes from these areas or removed nitrogen from piggery wastewater using treatment before landspreading. The two first options are more difficult because of economic, social and technical reasons.

Biological nitrogen removal by nitrification and denitrification, is generally believed to provide most economical means of controlling nitrogen in wastewater effluents (Coelho et al., 2000). Moreover, single-sludge wastewater treatment systems for biological nitrification/denitrification offer significant advantages over multiple-sludge systems in particular when the characteristics of the wastewater are very variable over time as observed with piggery wastewater (Béline et al., 2004). However, the design and the management of the treatment system must be optimise in order to meet the regulations and reduce treatment costs.

Due to process complexity, heuristic optimisation is rarely efficient and a model-based approach is often necessary (Coelho et al., 2000). The aim of this work was to developed such a model. For this purpose, an intermittent aeration process (IAP) pilot-plant was developed and some experiments were carried out in order to calibrate and validate the model.

MATERIALS AND METHODS

Pilot-plant description

The IAP pilot-plant is schematically represented in figure 1. The piggery wastewater was stored at 4°C during the whole experiment in a 500L tank (1). The 100L reactor (6) was equipped with a pump (8) allowing circulation of the liquid from the bottom to the top of the reactor for mixing the sludge during anoxic phase, and a fine bubble diffuser (15) for oxygen supplementation during aerobic phase. Air was supplied to the bubble diffuser by means of a membrane pump (11), and was cooled at room temperature through heat exchanger (12). The air flow rate was controlled and regulated through a flow meter (13) and a gas meter (14). A mechanical foam breaker (7) was installed on the top of the reactor. Tap water stored at room temperature (9) was continuously added to the reactor with a peristaltic pump (10) to compensate for evaporation. Before feeding the reactor, piggery wastewater was pumped with a peristaltic pump (2) from the storage tank to a smaller vessel (3) and was weighed with a balance (5). After the weight, a valve (4) was opened and allowed the feeding of the reactor with the wastewater. Discharge was achieved by means of a valve (17) and a level system (18) ensuring that the pilot sludge volume remained stable at 100L. The discharge was manually weighed with a balance (19) allowing to regulate tap water supplied to the reactor to ensure equal influent and effluent quantity. Temperature, pH, oxido-reduction potential (ORP) and dissolved oxygen (DO) probes (16) were installed in the reactor. The pilot-plant was fully automatic and managed by a computer (20) using Silab/Scicos software.

Analytical methods

Total solids (TS), suspended solids (SS), volatile suspended solids (VSS), chemical oxygen demand (COD) and total Kjeldahl nitrogen (TKN) were analysed by standard methods (APHA 1992). Soluble fraction (COD and Nitrogen) were obtained after centrifugation at 5000 rpm for 15 min. Total NH_4^+ was analysed by steam distillation using MgO followed by back titration of the boric acid distillates using sulphuric acid (0.1M). Soluble NH_4^+ , NO_2^- and NO_3^- were analysed by ionic chromatography on a Dionex DX120 system.

For the purposes of understanding and modelling, influent organic matter (expressed as COD) and nitrogen contents were divided in 4 fractions (Henze et al., 2000) defined as inert soluble, inert particulate, readily biodegradable, and slowly biodegradable. The fractions were determined using long-term BOD and respirometry tests (Boursier et al. 2004).

Experimental runs

The IAP pilot-plant operated on a daily cycle scheduled as follows:

- a feed phase at the beginning of each cycle: 10 kg of piggery wastewater was added to the reactor,
- an anoxic phase with mixing without aeration (240 min.),
- an aerobic phase with aeration (1200 min.),
- a discharge phase.

There was no settling phase at the end of the cycle resulting in a sludge retention time (SRT) equal to the hydraulic retention time (HRT) of 11 days. When a steady state was reached in the reactor (i.e. after more than 3 HRT), influent and effluent characteristics were determined. Two nitrogen studies analysing $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NO}_2\text{-N}$ in the reactor were performed over a daily cycle. The first study (run 1) was performed during normal operating conditions and have been used for processes investigation and model calibration. The second study (run 2) was performed two days later and ammonium carbonate (1 litre, 13.5 gN.l⁻¹) was added in the reactor in more of piggery wastewater during the feed phase. Run 2 was used for model verification.

Model structure and implementation

GPS-X software (Version 4.02) from Hydromantis Inc. was used to perform simulation of the IAP using piggery wastewater. The two-step mantis model was adapted as described in the

results section and was used for the IAP modelling. The reactor was modelled using an SBR with 4 phases as described in the experimental section.

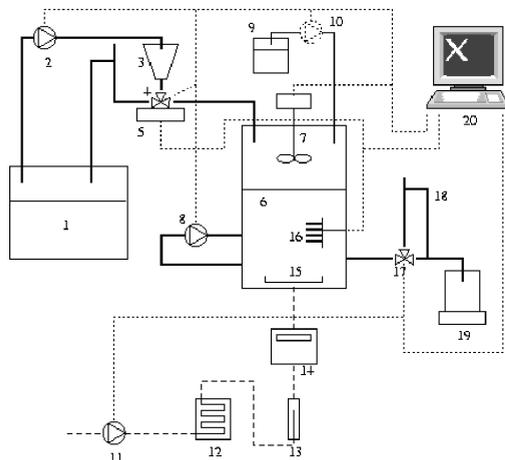


Figure 1. Schematic drawing of the pilot-plant.

RESULTS AND DISCUSSION

Piggery wastewater characteristics

Average characteristics of the raw and treated piggery wastewater are presented in table 1. As observed previously (Burton, 1992) IAP treatment can remove 86 and 61% of soluble COD and total nitrogen, respectively.

Table 1. Average piggery wastewater characteristics before (influent) and after (effluent) IAP treatment.

	TS kg.m ⁻³	SS kg.m ⁻³	VSS kg.m ⁻³	Total COD kg O ₂ .m ⁻³	Soluble COD kg O ₂ .m ⁻³	NH ₄ ⁺ kg N.m ⁻³	TKN kg N.m ⁻³	NO ₂ ⁻ +NO ₃ ⁻ kg N.m ⁻³
Influent	54.0	42.5	31.9	50.6	21.8	3.0	4.6	-
Effluent	44.0	37.6	28.5	42.1	3.0	0.0	1.8	0.3
Removal (%)	18.5	11.5	10.6	16.8	86.2	100.0	60.9	-

Nitrogen removal processes

Di-nitrogen (N₂) produced by denitrification during the anoxic phase was estimated considering the difference between [NO₂-N + NO₃-N] at the beginning and the end of the anoxic phase. Calculated N₂ represented more than 85% of nitrogen removed during the treatment. This result indicated clearly that nitrogen removal by ammonia emissions and/or simultaneous nitrification/denitrification was low during this experiment.

As indicated in figure 2, both nitrification and denitrification processes produced NO₂⁻ as an intermediate. Indeed, NO₂⁻ concentrations up to 100 mg N.l⁻¹ was observed during the anoxic and oxic phases. These results highlighted the different kinetics during nitrification between oxidation of NH₄⁺ and NO₂⁻ and during denitrification between reduction of NO₃⁻ and NO₂⁻.

Modelling of IAP treatment

According to the results obtained during this experiment and previous results (Boursier

2004), the two-step mantis model was modified as follows:

- only one slowly biodegradable fraction (Xs) directly hydrolysed to readily biodegradable compounds (Ss) was considered,
- the hydrolysis process of Xs was no surface-limiting,
- anoxic and oxic heterotrophic yields were different at 0.53 and 0.6 gCOD.gCOD⁻¹, respectively,
- during denitrification, NO₃⁻ were firstly reduced to NO₂⁻ and then to N₂.

Kinetics and stoichiometric constants were manually calibrated using the results of run 1 (Figure 2a). The same kinetic and stoichiometric constants were used to simulate nitrogen transformations during the run 2 (Figure 2b). Results show good agreement between experimental and modelling data and allow us to validate the model.

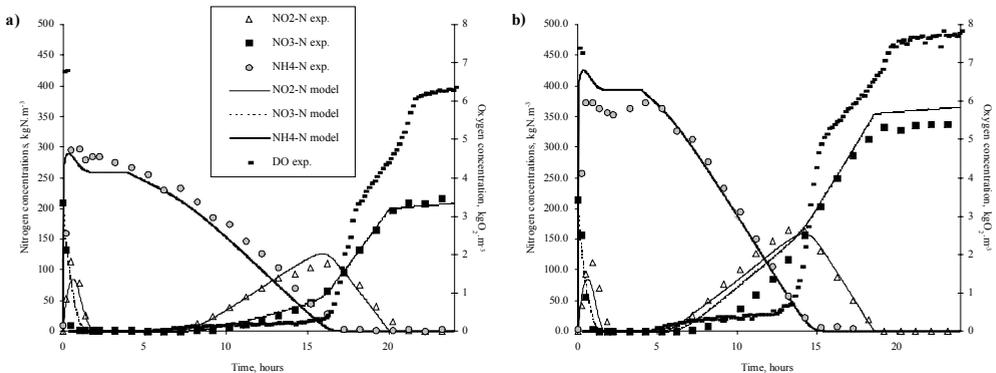


Figure 2. Experimental and model nitrogen (NH_4^+ , NO_2^- and NO_3^-) and oxygen concentrations in the reactor during a daily cycle of piggery wastewater treatment (a: run 1, b: run 2).

CONCLUSIONS

During this work, experimental data obtained during piggery wastewater IAP treatment were used to develop and calibrate a mathematical model to simulate nitrogen and organic matter transformations. The model developed simulated successfully both experiments performed. This model should be used to optimize design and management of piggery wastewater IAP treatment.

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