Liquid pig manure treatment in a farm plant : fate of polluting elements before and during storage in a shallow lagoon.

Traitement du lisier de porc à la ferme : devenir des éléments polluants avant et au cours du stockage en lagunes peu profondes.

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Abstract

The treatment scheme is based on centrifuge sieving, decantation-biodegradation in two shallow lagoons and finally land spreading. The fate of potentially polluting elements (organic carbon, nitrogen, phosphorus, Zn and Cu) was studied all along the treatment process. Centrifuge sieving capacity is 22.4 $m^3.h^{-1}$ and is able to remove 42.9% of the dry matter and 26.5% COD, but only 4.8 % total N and 9% of P, Cu and Zn. From the 38.4 t N $year^{-1}$ entering in the first lagoon, 6.3 t settle in the sediment and 7.6 t are eliminated by ammonia volatilization and/or nitrification-denitrification ; the respective part of each mechanism is not defined. The sediments collected in the lagoon contained, on average, 3.3 % N, 5.5 % P on dry matter basis. However Cu and Zn contents are higher than 0.1 and 0.3%, values considered as maximal admissible concentrations.

Keywords : Liquid pig manure, lagoon storage, organic matter, nitrogen, phosphorus, copper, zinc, biopurification

Résumé

La filière de traitement comprend un tamis centrifuge, une décantation-biodégradation dans deux lagunes peu profondes et se termine par un épandage agricole. Le devenir des éléments polluants (carbone organique, azote, phosphore, zinc et cuivre) a été étudié au cours du process de traitement. La capacité du tamis centrifuge est de 22.4 m3.h-1 et permet l'enlèvement de 42.9 % de la matière sèche et 26,5% de la DCO, mais seulement 4,8% de N total et 9% de P, Cu et Zn. En ce qui concerne l'azote, 38.4 t an-1 entrent dans la première lagune, puis 6.3 t décantent dans les sédiments et 7.6 t sont éliminées par volatilisation d'ammoniac et/ou nitrification-dénitrification ; la part respective de chaque mécanisme n'est pas définie. Les matières sèches des sédiments collectés dans la lagune contiennent, en moyenne, 3.3% de N et 5.5% de P. Cependant les teneurs en Cu et Zn sont supérieures aux concentrations maximales admissibles qui sont respectivement de 0.1 et 0.3%.

Mots-clés : lisier porc, stockage lagune, matière organique, azote, phosphore, cuivre, zinc, méthane, bio-traitement.

1. Introduction

Animal manures represent very large volumes of waste. They are traditionally used for landspreading in agriculture and provide important sources of organic matter and fertilisers. In France such manures represented in 1990 32.6 % of the nitrogen and 30 % of the phosphorus used in agriculture (IFEN, 1994-95). Pigs produce 116000 t of nitrogen and 51000 t of phosphorus annually (Théobald, 1997; from Leroy, 1994).

A slurry-treatment plant has been in operation for several years on a pig farm in the Dijon area. It is based on phase separation by centrifuge sieve and storage in shallow basins. The resulting slurry is then spread on the arable land on the farm.

An experimental nitrogen-treatment unit, consisting of a trickling filter on a gravel bed (Senez et al., 1997) and a denitrification reactor has been added to this system following laboratory studies (Boiran et al., 1996). Definition of the best way of integrating this experimental system into the other steps of the operation, necessitates a thorough understanding of the existing treatment system, especially of the changes occurring in the slurry in the shallow basin.

This study was therefore aimed to assess the current system and, more especially, to i) calculate the piggery effluent fluxes, ii) measure the efficiency of phase separation, and iii) determine the fate of the products during lagoon storage (sedimentation and biopurification). These assessments concern the organic matter or COD, nitrogen and phosphorus. The fate of other elements (K, Na, Cl, Cu and Zn) was also investigated.

2. Material and methods

2.1. The piggery and system of treatment

This pig farm is associated with large-scale arable cropping. There are three types of activities: breeding to obtain reproducers, piglet production and fattening of pork pigs. 7300 pork pigs are produced and 400 sows and boars are present throughout the year. The estimated effluent produced by the piggery is equivalent to that of a pig farm with an annual production of 10760 pork pigs.

Figure 1 shows the different stages of slurry treatment. The pigs are reared on a slatted floor. A 152 m^3 pit collects the manure and waste water and is emptied twice a week after forced recirculation of the slurry. A centrifuge sieve (Demoisy, 21200 Beaune) fitted with grid of 100 μm mesh retains a part of suspended particules ; the collected material is composted. The slurry moves by gravitational flow towards the lagoons which consist of two water-tight basins, each 3180 m^2 and 6000 m^3, placed in series and allowing storage for more than six months. The slurry from the second basin is then spread on the soil by specially adapted sprinklers, if necessary after dilution. In summer when the liquid phase has been emptied, the sludge that has accumulated in the first lagoon is then removed for spreading.

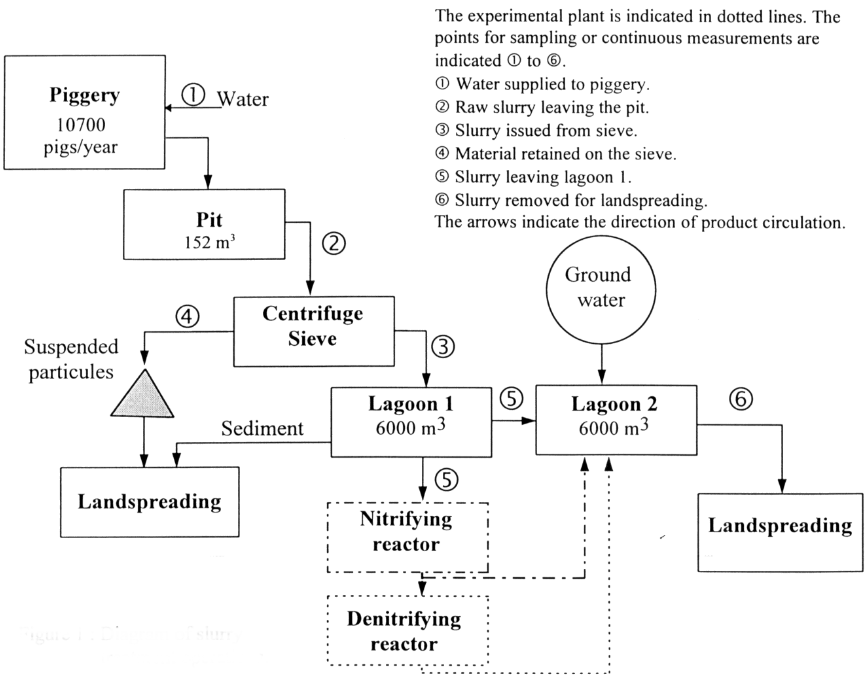

Figure 1
Diagram of slurry treatment operations.

2.2. Measurements of liquid fluxes

The levels of dilution in the different parts of the system are determined by monitoring the concentrations of chloride tracers.

2.2.1. Slurry produced in the piggery and processed on the sieve

The water consumption is measured by meters and the amounts of slurry produced by the piggery calculated in two ways : i) from the sieving time and the mean flow rate at the sieve outlet, ii) from variations in the liquid volumes measured with limnimeters in the lagoons and after correction for rainfall. In both cases, the solid material refused by the sieve is taken into account.

Efficiency of the sieve separation was measured on four different days (13-2-96; 29-3-96; 28-6-96 and 25-3-97) from the mean flow-rates. These were calculated by measuring the volume variations in the collecting pit on the one hand, and the filling times of a calibrated container placed at the sieve outlet on the other hand, and by weighing the retained solid material. Weekly samples were taken of slurry from the collecting pit, after homogenisation, and of the slurry passing through the sieve.

2.2.2. Evolution of the slurry in the first lagoon

The slurry entering the lagoon came directly from the sieve. The liquid flux across the first basin was evaluated as previously indicated. Samples of slurry were taken at the lagoon outlet at least once a week.

The measurements of flux were completed with two series of samples to determine the state of the first lagoon in winter and summer, on February 1st and July 25th 1996. The volumes of liquid and sediment were calculated using the Simpson formula (Saïac, 1989) from topographic readings at the bottom of the basin based on 55 points and measurement of the height of the liquid with a probe applying a pressure of 1000 Pa to the top of the sediment at 134 points.

2.3. Elements monitored and analysed

The dry matter and total concentrations of the different elements were measured in the raw slurry samples, whereas the soluble elements and the suspended matter were determined after centrifugation (1000 G, 20 min). The COD was determined by AFNOR NF T 90 101 method, total nitrogen by the Kjeldahl method where necessary after nitrate reduction with iron. The mineral forms of nitrogen, orthophosphate and chloride were determined by colorimetric analyses in continuous flux (APHA, 1985). After mineralisation of the dry matter at 450°C and taking up the ash in acid medium the total phosphorus was determined by continuous flux analysis, the magnesium, copper and zinc by atomic absorption spectrometry, and the calcium, potassium and sodium by flame photometry.

3. Results and discussion

3.1. Overall liquid and solid phase assessment

3.1.1. Feed input and slurry production

Between March 1st 1996 and February 28th 1997, the piggery consumed 19000 m^3 of water and 2390 t of feed with a 12 % moisture content, which provided 65 t of nitrogen, 28 t of calcium and 16.8 t of phosphorus. The mean consumption of 52 m^3 of water per day was associated with a slurry production of 47 m^3 day^{-1} (measured at the pit outlet) i.e. 1.6 m^3 of slurry per pig equivalent. This is a much higher value than the values of 0.7 to 0.8 m^3 habitually quoted in France. These slurries are highly diluted.

3.1.2. Centrifuge sieve

The mean flow-rate measured at the outlet of the centrifuge sieve on 4 different days was 22.4 m^3 h^{-1}. The sieve retained 42.9 % dry matter and 47.9 % of the suspended matter in the refused solid with an initial moisture content of 75 %.

3.1.3. Lagoons

The liquid flux within the lagoon calculated from the volume variations measured throughout the year and corrected for precipitation was 17466 m^3, which in view of the relative uncertainty of the measurements corresponded, moreorless, to the volume of slurry (16475 m^3) leaving the sieve.

Comparison of the loads at the inlet and outlet of the first basin showed that 248 t of dry matter per year could be retained by decantation and purification. The sludges deposited at the bottom of the basin had dry matter contents of 256 $g.l^{-1}$ in winter and 231 $g.l^{-1}$ in summer and were highly mineralised, with an average ash/dry matter ratio of 64 %.

In winter the separation between supernatant and decanted phase was clearly defined. On February 1st 1996 the first basin contained 4036 m^3 of liquid resting on 1463 m^3 of sediments. It was less obvious in summer. On July 25th 1996 this same basin contained 1228 m^3 of sediments and 3711 m^3 of supernatant liquid in which 2 strata could be distinguished. The first, to 50 cm in depth, was a highly decanted liquid whereas the second, between -50 cm and the sediment surface, was an intermediate zone with an increasing gradient of suspended matter corresponding to resuspension of the sediments.

3.2 Fate of the products in lagoon

3.2.1. Organic matter (COD)

The liquid manure leaving the piggery represents an annual effluent of 643 t of COD i.e. on average 59.7 kg COD per pig-equivalent, which is similar to the reference value of 58 kg per pig (Héduit, 1990). The centrifuge sieve holds back 28.1 % of this organic load i.e. 181 t $COD.year^{-1}$.

Therefore the first lagoon received 462 t of COD for one year; assessment of the COD fluxes at the inlet and outlet revealed a reduction of 386 t during lagooning i.e. 83.5 % of the supplied amount. Between February 1st and July 25th 1996, the increased amount of organic matter in the first lagoon corresponded to a little more than half (53 %) of the difference in load between the input and the output, the other half (47 %) being considered as purified. If these ratios are applied to the entire year, the purified COD becomes 181 t, i.e. a yield of 57 kg $COD.m^{-2}. year^{-1}$ or 156 g $COD.m^{-2}.day^{-1}$, corresponding to 58.5 g $C.m^{-2}.day^{-1}$.

In April 1977 we measured 62 g $C.m^{-2}.day^{-1}$ released as biogas at the lagoon surface (70 % CH_4-C, 30 % CO_2-C). This data concords with the previously estimated purifying capacity and confirms that methanisation is the principal mechanism of organic matter elimination. Application of this level of 70 % to 181 t of purified COD provides an estimate of 63 t of methane released over one year or 76 $l.m^{-2}.day^{-1}$. This is double the amount measured by Safley et al. (1989). These methane emissions are certainly considerable but need to be evaluated over a longer period as methane production is highly dependent on temperature (Safley et al., 1989; Yang et al., 1997).

The amount of organic matter in solution removed for landspreading therefore represents no more than 11.8 % of the organic matter produced by the animals. A greater part was left in the compostable solid material that remained on the sieve (28.1 %) and in the sludges at the bottom of the basin (31.9 %) which are also destined for landspreading but require separate management (table 1).

	$t.yr^{-1}$	% of effluent
annual piggery effluent	643	100.0
retained on the sieve	181	28.1
decanted in the lagoon	205	31.9
purified in the lagoon	181	28.1
removed for spreading	76	11.8

Table 1
Fate of the organic matter content (COD) during the treatment operations

3.2.2. Nitrogen

The feeds supply 65 t of nitrogen per year. The nitrogen effluent estimated from measurements at the storage pit outlet was 40.6 $t.year^{-1}$, that is 62.5 % of that supplied, with a low mean concentration in accordance with the diluted nature of the slurry : 2.4 $g.l^{-1}$ of total nitrogen with 1.3 $g.l^{-1}$ i.e. 54 % in ammoniacal form..

The centrifuge sieve retains little nitrogen: the concentration reduction of the liquid phase was only 2.9 % and when the liquid phase associated with the particles was taken into account, 4.8 % of the nitrogen, that is 2.2 t per year, were found to be retained in the material refused by the sieve, which, prior to composting, is therefore relatively poor in this element.

The nitrogen decanted in the sediments during the year was estimated using P, Cu and Zn as tracer elements : the amounts decanted were determined from the inputs and outputs of these elements, and the mean nitrogen ratios with each of them in the sediment to evaluate the amount of nitrogen retained (Senez et al., 1997): the values obtained varied between 5.3 t and 7.3 t depending on the tracer: the intermediate value of 6.3 t was retained. The difference between the previously indicated 13.9 t and the 6.3 t corresponds to the nitrogen that has been purified or volatilised, i.e. 7.6 t N. $year^{-1}$ or 6.55 g N. $m^{-2}.day^{-1}$.

A point estimate of the ammonia volatilised in April 1997 indicated 0.58 $g.m^{-2}.day^{-1}$ of NH_3-N. This value is low and should be compared with the volatilization values of 1.53 g NH_3-$N.m^{-2}.day^{-1}$, measured by Schilton (1996) and 0.33 to 4.15 g NH_3-$N.m^{-2}.day^{-1}$

obtained by Sommer et al. (1996) over basins 20 to 200 cm in depth. In the present case and in the absence of more numerous measurements, it was not possible to distinguish between the purified nitrogen and the volatilised nitrogen.

The collected data as a whole can be used to tabulate the measurements and estimates of the different transformations. It is apparent that the liquid phase taken from the lagoon and used for spreading only contains 53.8 % of the nitrogen excreted by the animals. When assessing the quantities applied to the land the 4.8 % i.e. the material that did not pass through the sieve and the 13.8 % i.e. the sludge decanted at the bottom of the basin, which require separate management, also need to be included (Table 2).

		$t\ N.yr^{-1}$	% excreted N
1	nitrogen supplied in the feed*	65.0	
2	nitrogen retained by the animals (30 % of 1)**	19.5	
3	nitrogen excreted by the animals (1-2)**	45.5	100.0
4	nitrogen leaving the storage pit***	40.6	89.2
5	volatilisation under the animals (3-4)**	4.9	10.8
6	retained on the sieve ***	2.2	4.8
7	decanted in the lagoon**	6.3	13.8
8	purified or volatilised in the lagoon **	7.6	16.7
9	removed for landspreading***	24.5	53.8

* estimated from farmer's data; ** estimated from ratios and calculations; *** estimated from measurements made during this study.

Table 2

Fate of the nitrogen content during the treatment operations

3.2.3. Phosphorus

The phosphorus in the slurry is essentially in particulate form : the mean total P concentration at the pit outlet was 850 $mg.l^{-1}$ whereas the soluble fraction was only 55 $mg.l^{-1}$, i.e. of the same order of magnitude as in the lagoon supernatant. In spite of this particulate character, little phosphorus (9.1 %) is retained by the centrifuge sieve, thus indicating its presence in the finest particles. Considerable decantation occurs in the lagoon, representing 90 % of the input and 82 % of the excreted phosphorus (Table 3). However the mean concentration in the sediments, 5.5 % of the dry matter, is indicative of the value of the decanted product as a fertiliser.

	$t.yr^{-1}$	% of effluent
annual piggery output	14.2 t	
retained on the sieve	1.3 t	9.1%
decanted in the lagoon	11.6 t	81.7%
removed for land-spreading	1.3 t	9.1%

Table 3

Fate of the phosphorus content during the treatment operations.

3.2.4. Other elements

The initial piggery effluent contains 15.5 t of potassium, 26.8 t of calcium, 4 t of magnesium and 3.9 t of sodium. The sodium and potassium do not undergo any transformation during their passage through the system and almost all can be found in the liquid to be used for land-spreading. The calcium and magnesium are decanted in the lagoon where their respective mean concentrations are 13.9 % and 2.3 % of the dry matter.

The concentrations of copper and zinc exhibit the same evolution as phosphorus during their passage through the system. Only 9 % of their mass is retained in the material refused by the centrifugal sieve. Most of these heavy metals, i.e. 82 % of the amounts excreted are decanted in the bassin and only 9 % are removed with the liquid phase for land-spreading. The copper and zinc contents of the sediments are higher than the maximal values admissible for urban sludge (1000 mg $Cu.kg^{-1}$ and 3000 mg $Zn.kg^{-1}$ on dry matter basis).

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