PIG SLURRY TREATMENT STRATEGY IN A HIGH LIVESTOCK CONCENTRATION AREA: ANAEROBIC DIGESTION AS THE KEY PROCESS

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Abstract

A pig slurry treatment strategy must include processes with the aim of reducing volatile organic compound emissions, controlling odours, mineralising nutrients, improving its fertilising proprieties, and recovering energy, when it is possible. In this sense, anaerobic digestion fulfils all this requirements. However, in areas with high animal farming density and a structural nutrient surplus, it is necessary to include other processes, which favour nutrient redistribution. The objective of this paper is to study the importance of including anaerobic digestion process in the treatment strategy when the main objective is to recover nitrogen by means of ammonia air stripping at 80ºC, or by vacuum evaporation in order to reduce volume and to favour redistribution. Two types of pig slurry (fresh and anaerobically digested slurry) were used and the initial pH was chosen as the control variable. Apart from producing part of the required thermal energy, previous anaerobic digestion presented several clear advantages: The consumption of volatile fatty acids and volatile organic compounds during anaerobic digestion reduced the volatilisation of organic matter in the stripping and vacuum evaporation processes. This fact resulted in high quality condensate when vacuum evaporation is applied and an ammonia salt with low organic matter contamination when nitrogen is recovered with stripping / absorption process. In this case, high ammonia removal efficiency is possible, over 96%, without modifying the pH.

Keywords

Anaerobic digestion, pig slurry, pre-treatment, post-treatment, ammonia stripping, vacuum evaporation

Introduction

A treatment strategy of a given type of waste is a combination of several processes with the objective of obtaining profitable products, recovering energy and raw materials and minimizing negative environmental effects. The strategy definition depends on the composition of the waste, on local circumstances, and on the required quality for the end products.

For pig slurry, the inclusion of anaerobic digestion in the treatment strategy offers several advantages: preventing volatile organic compound emissions, controlling odours, mineralising nutrient and recovering energy through methane production. However, in geographical areas with high animal farming density a supplementary process with the aim of reducing volume and/or recovering nutrients has became a need.

It should be also taken into account that when energy cogeneration is applied, the feasibility of the process is also dependent on profitable uses of the recovered head. Profitable uses of this energy fraction are a limiting factor in warm countries. The use of the surplus thermal energy for pre-treatments, in order to improve anaerobic digestion, has been demonstrated as a good way of promoting the economic and energetic advantages of anaerobic digestion implementation and operation (Bonmatí *et al.*, 2001)

Since nitrogen is the nutrient that generally limits the amount of manure that can be applied to the soil, nitrogen removal and/or recovery is relevant for improving management in areas with a structural nitrogen surplus. Treatments for recovering nitrogen from livestock waste are appropriate since they tend to close the nitrogen cycle (allowing the recovered product to be recycled into the agricultural system) and thereby to save energy. In this sense, air stripping in combination with absorption could be and interesting option.

Another strategy for improving pig slurry management is its redistribution between areas with nutrient surplus and those with shortage. However, this is limited by transportation and spreading costs due to the high water content of the slurries and their relatively low nutrient concentration. Treatments as vacuum evaporation, which aim to reduce volume, economically favour redistribution. The existence of a cheap source of thermal energy is probably the main limitation in the case of evaporation. In this sense, the Spanish Royal Decree 2818/98 favours economically the use of waste heat from electrical power plants for organic waste volume reduction.

In the present paper, it will be analysed the importance of the inclusion of anaerobic digestion in the treatment strategy when the main objective is to recover nitrogen, applying ammonia air stripping, or to reduce volume by vacuum evaporation for favouring redistribution.

Two flow diagrams of nitrogen recovery strategy were compared, including or not anaerobic digestion (Figure 1).

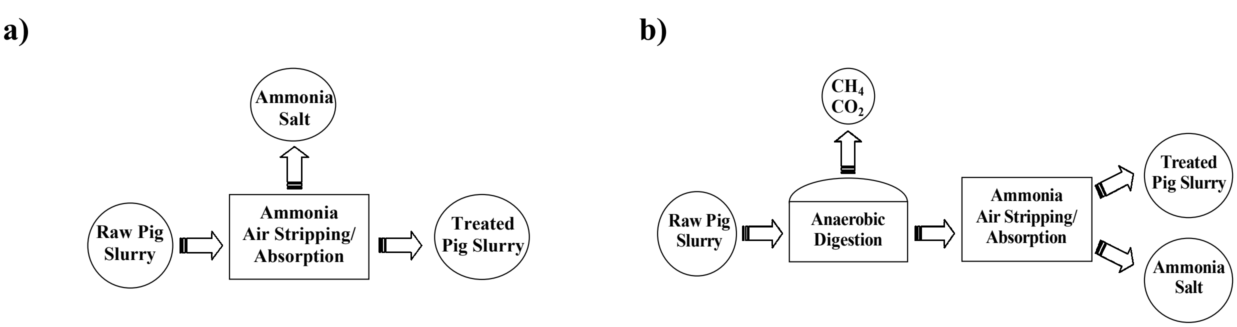


Figure 1 Nitrogen recovery strategy: a) ammonia air stripping and b) anaerobic digestion and ammonia air stripping.

As well as in nitrogen recovery strategy, two flow diagrams were compared in the reduction of volume strategy (Figure 2).

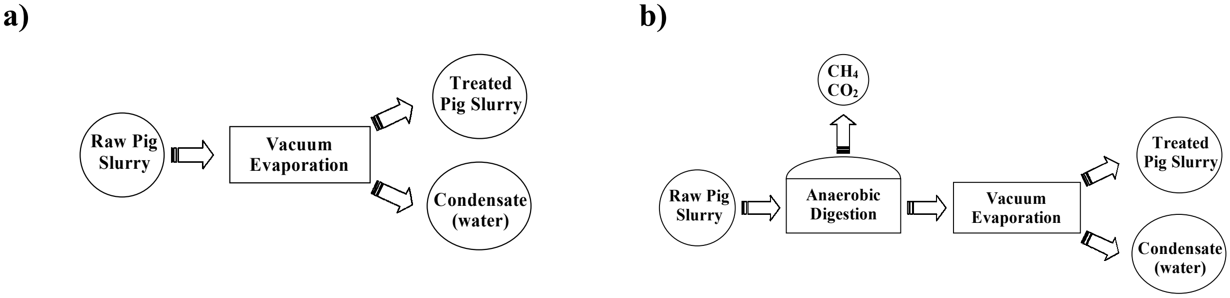


Figure 2 Reduction of volume strategy: a) vacuum evaporation and b) anaerobic digestion and vacuum evaporation.

Material and methods

Two different experiment were conduced: ammonia air stripping / absorption experiments and vacuum evaporation experiments.

Ammonia air Stripping / Absorption experiments

A semi-continuous lab scale ammonia air stripping / absorption system was constructed an operated (Bonmatí and Flotats, 2002a), in order to compare the feasibility of ammonia air stripping as a pre- or post-treatment to mesophilic anaerobic digestion.

Two different pig slurry (fresh pig slurry and anaerobic digested slurry, see Table 1) were used at three different initial pHs (non-modified, 9.5 and 11.5). pH adjustment was made by calcium hydroxide. Pig slurry was previously filtered through a 200 µm sieve. Temperature was set at 80ºC. Sulphuric acid was used in the absorption process. The feasibility of the operation (% ammonia removed and the removal rate) and the characteristics of the ammonia salt obtained were used to compare the treatment strategies.

Table 1 Characterisation of the filtered pig slurry used in ammonia air stripping experiments (average of three samples)

	pH	TS (g/kg)	VS (g/kg)	COD (g/kg)	NH_4^+-N (g/kg)	TKN (g/kg)	VFA (g/kg)
Fresh Slurry	7.5	52.97	35.18	70.59	3.39	5.63	10.84
Digested Slurry	8.4	31.72	17.17	41.23	3.68	4.73	0.24

Vacuum evaporation experiments

The inclusion of anaerobic digestion previous to the evaporation process was studied by means of the characteristic of the condensate recovered in a batch lab scale evaporator (Bonmatí and Flotats, 2002b).

As in air stripping experiments, two different slurry types were used (fresh pig slurry and anaerobically digested slurry, see Table 2) and three initial pHs (4, 5, and 6). pH adjustment was made by sulphuric acid. Pig slurry was also filtered through a 200 µm sieve. Temperature was set at 40ºC and pressure at 50 mmHg.

Table 2 Characterisation of the filtered pig slurry used in vacuum evaporation experiments (average of three samples)

	pH	TS (g/kg)	VS (g/kg)	COD (g/kg)	NH_4^+-N (g/kg)	TKN (g/kg)	VFA (g/kg)
Fresh Slurry	7.7	49.06	30.94	68.78	3.51	5.80	14.85
Digested Slurry	8.5	15.71	8.61	13.11	1.96	2.59	0.62

Analytical methods

Total Kjeldahl nitrogen (TKN), ammonia nitrogen, pH, total solids (TS), volatile solids (VS), and chemical oxygen demand (COD) were all analysed by standard methods (APHA, 1995). Volatile fatty acids (VFA) were analysed by capillary gas chromatography with a Flame Ionised Detector (FID).

Statistical methods

Statistical analysis was performed using SAS software (SAS Institute, 1989). A one way ANOVA test was carried out. When this analysis indicated significant differences and interaction was significant, Last Square Means test was performed with a significance level of 5%.

Results and discussion

Ammonia air Stripping / Absorption experiments

Ammonia removal efficiencies are presented in Table 3. As it can be seen, in all cases percent ammonia removal is greater in experiments with digested slurry than those with fresh pig slurry, except when initial pH was set at 11.5. Final ammonia concentrations below 0.12 g/kg, and ammonia removal efficiencies above 96%, were reported in all treatments with digested slurry. It is possible to completely remove ammonia without pH modification when using digested slurry. This was in accordance with Collivignarelli *et al.* (1998), who reported experiments performed with an old landfill leachate showing that it was possible to achieve high ammonia removal efficiencies without base dosage, if temperature was maintained at between 60 –70ºC.

The different behaviour of the two slurry types could be attributable to the different concentration in VFA (Table 1). The high content of VFA in fresh slurry leads to a fall in pH during the stripping process. A pH decrease of between 0.8 – 3.1 was reported in fresh slurry experiments. This fall in pH results in lower ammonia removal efficiencies in fresh slurry experiments than in digested slurry experiments. Low pHs reduced ammonia volatility by shifting its dissociation reaction towards the ionic form (Perry , 1992).

Table 1 Ammonia removal efficiency (%) in ammonia air stripping experiments

	Initial pH		
	Non-modified	9.5	11.5
	% Ammonia removal		
Fresh slurry	65.0	69.0	98.8
Digested slurry	96.0	99.2	97.0

As seen in Figure 3, the different pH levels had different effects on ammonia removal rates, according to the substrate. In the experiments performed with fresh pig slurry, although the initial pH was set at 9.5, ammonia removal rates did not increase significantly (letters a-c in Figure 3). A high initial pH (11.5) was necessary to obtain a significant increase in the ammonia removal rate. The anaerobically digested slurry showed different behaviour. On seating the initial pH at 9.5 the ammonia removal rate increased significantly, but no further increase was reported when initial pH was set at 11.5.

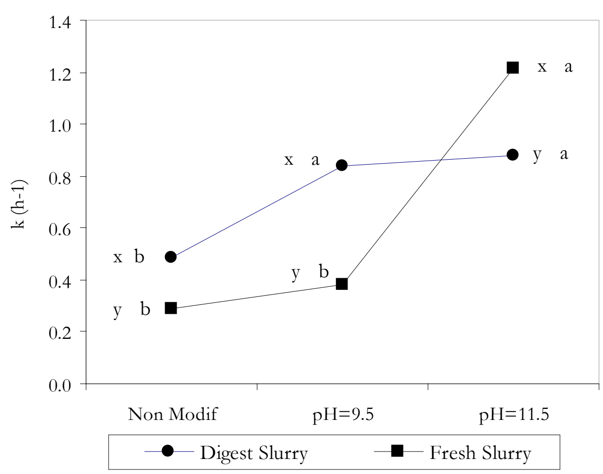


Figure 3 Ammonia removal rates for the different pHs and substrate types. Values with the same letter are not statistically different at 5% level of significance. Letters "a to c" are used to compare initial pHs for the same substrate, letters "x to z" are used to compare substrates with the same initial pH

The water containing ammonia salt obtained in the absorption process was crystallized. The characteristics (colour and COD) of the crystallized ammonia salt differ between the two slurry types. The higher COD of the water ammonia salts coming from the fresh pig slurry resulted in a darker colour than that from digested slurry.

These results showed that ammonia air stripping has many advantages if it is performed as a post-treatment to pig slurry anaerobic digestion. It is possible to achieve high ammonia removal efficiencies without pH modification and COD low contaminates the ammonia-salt water obtained in the absorption process.

Vacuum evaporation experiments

Condensate characteristics as a function of the initial pH are showed in Figure 4. As expected, the higher the initial slurry pH, the higher ammonia concentration in the condensate, and the lower the initial pH, the higher total volatile fatty acids (VFA) concentration in the condensate. This is in accordance with theoretical studies performed by Marks *et al.* (1994). Both types of slurry present the same pattern.

COD present different behaviour depending on the type of slurry. In fresh slurry experiments, COD in the condensate increased when pH decreased. The COD associated with VFA represented 27% of the total COD. On the other hand, in experiments with digested slurry, no relationship was found between COD and the initial pH. This suggests that the volatile organic matter of the digested slurry was mainly composed of non-ionised compounds, and pH did not affect its volatilisation. The VFA concentration of the slurry only represented the 1.5% of the total COD.

It should also be noted that, at a given pH, ammonia nitrogen, COD and VFA concentration in the condensate from fresh slurry were higher than those from digested slurry (Figure 4). This is in accordance with the higher ammonia nitrogen, COD and TVFA concentration of the fresh slurry than the digested slurry (Table 2).

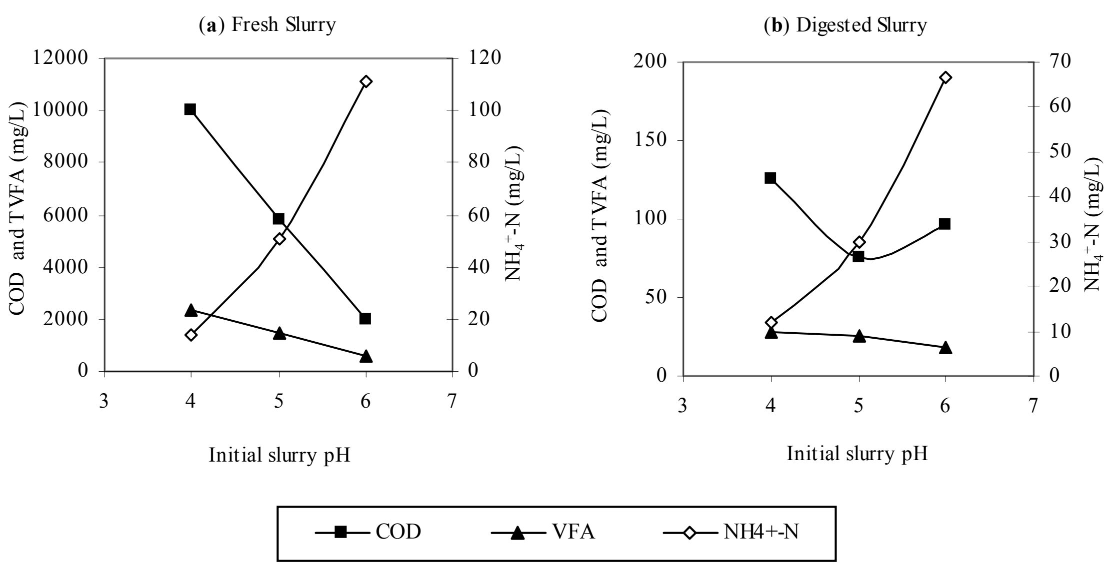


Figure 4 Ammonia nitrogen, COD and VFA concentration on the condensate as a function of the initial slurry pH: (a) experiments with fresh slurry, (b) experiments with digested slurry

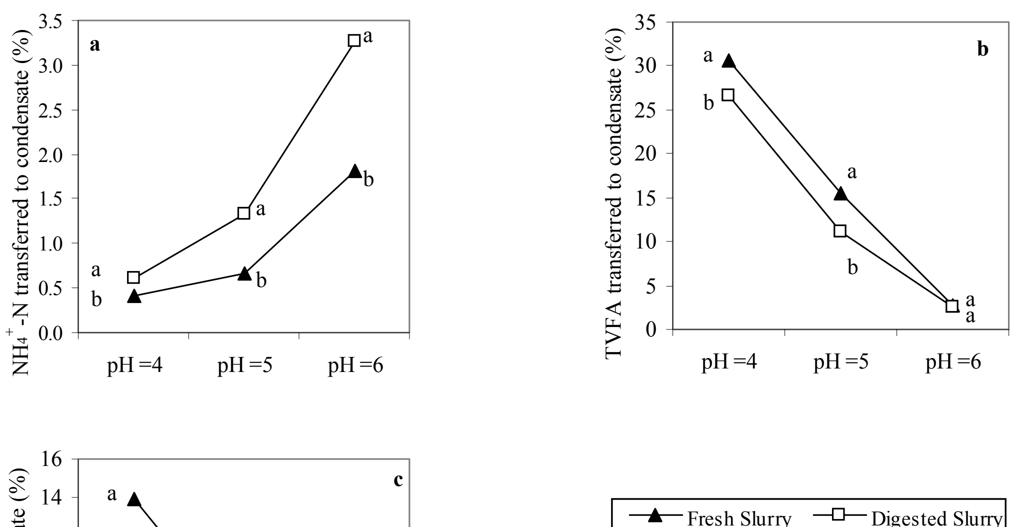
In order to avoid the effect of the initial slurry concentration and to compare the behaviour of the two slurry types, the percent mass transferred to the condensate was calculated.

The percent of volatile fatty acids transferred to the condensate was higher in experiments with fresh slurry than those with digested slurry (Figure 5b). In contrast, percent ammonia nitrogen transferred to the condensate in experiments with digested slurry was larger than in those with fresh slurry, for all initials pHs tested (Figure 5a).

This fact can be explained by the final pH of the concentrate. An increase of between 0.3 and 1.9 was observed depending on the initial pH and the type of slurry involved. This pH increase was higher in the experiment performed with digested slurry than in those with fresh slurry. This showed that when using a fixed initial slurry pH, the fraction of un-ionised VFA and ammonia nitrogen of the two slurry types were different, and explained the differences observed in the percentages of the compounds transferred.

In all cases, the COD% transferred to the condensate in the experiment with fresh slurry was larger than that reported in those with digested slurry (Figure 5c). The different nature of the organic matter of the slurries may explain this fact.

It can be concluded that under these operational conditions and within this range of pH values, a one-stage evaporation treatment would be sufficient to obtain high quality condensates if a previous anaerobic process is applied.



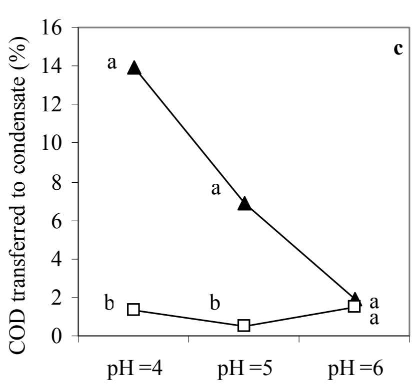


Figure 5 Ammonia nitrogen (a), VFA (b) and COD (c) transferred (%) to the condensate in the batch evaporation experiments. With the same initial slurry pH, different letters show significant differences between means (5% significance)

Conclusions

Previous anaerobic digestion of the slurry presents clear advantages for ammonia air stripping and vacuum evaporation. A part of providing part of the thermal energy needed for the studied processes, the conversion into CH_4 and CO_2 of most of the volatile organic improves the global treatment operation. It is possible to achieve high ammonia removal efficiencies without base dosage and the ammonia salt obtained in the stripping process is less contaminates when slurry has been previously anaerobically digested. The obtained condensates in the evaporation process also present lower concentrations of COD and VFA when a previous anaerobic digestion process is performed.

Those results showed that anaerobic digestion is a necessary step in a global pig slurry treatment strategy. A part of the well know benefits of anaerobic digestion, the inclusion in the treatment strategy improves the treatment operation, and the quality of the end products obtained.

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