THE INFLUENCE OF HYDRAULIC RESIDENCE TIME ON THE TREATMENT OF CATTLE MANURE IN UASB REACTORS

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Abstract

Cattle manure from farms in the Autonomous Community of Asturias, Spain, was characterised and subsequently treated, after filtration through a 1 mm sieve, in upflow anaerobic sludge blanket laboratory reactors. The volume generated per cow and day varied between 50-55 litres (obtained through a survey of 400 farms), the manure being used on Asturian farms up until now as a fertiliser. After screening, the COD of the manure employed varied between 33,000 and 56,000 mgO_2/l. The highest percentage of COD removal obtained was 75.5% for a hydraulic residence time of 22.5 days. Gas production varied between values of 0.20-0.39 m^3gas/Kg COD removed, with a methane content of up to 64%. There was a fraction refractory to biodegradation of 11%.

Key words: Farms, cattle manure, anaerobic treatment, upflow anaerobic sludge blanket (UASB).

1. Introduction

Traditionally, cattle farm waste, both in its solid as well as liquid form (manure), has been systematically applied to fields, thus fulfilling an essential role as fertiliser. However, wherever the cattle load exceeds the capacity of the surrounding farmland soil to absorb manure, environmental problems of pollution arise (Farrell. 1996; Iglesias 1995).

Asturias is an Autonomous Community of Spain with a large population of bovine cattle that produces milk and meat (in 1996 there were 14,220 cows that produced milk and 20,354 that produced meat (Proyecto Arcade 1997)).

In general, the greatest concentration of farms that produce milk (the most problematic since the cows are usually kept in stables) is found in the areas near to the coast where the elimination of cattle manure by means of its use as a fertiliser may lead to environmental problems.

1.1. Characteristics and treatment of manure

Cattle manure results from the solid and liquid waste produced by the cows. The volume generated and its composition (Barnett 1994; Fundación "La Caixa" 1993; Kirchmann & Witter 1992) generally varies from one farm to another, the main factors influencing the amount of cattle manure generated and its composition being the type of cattle, the type of feed, environmental conditions such as the addition of rainwater or water used for cleaning out the stables, as well as the duration and conditions of storage. However, it may be affirmed that the manure from cattle is a material with an abundant amount of organic matter, rich in nitrogen, potassium, calcium and phosphorous. It also contains variable amounts of sulphides, sulphates and chlorides along with oligoelements and trace heavy metals, among which the principal ones are generally Fe, Mn and Zn.

Prior to the anaerobic treatment study, a survey was carried out of 400 farms in the Asturian Community, the aim of which was to ascertain the volume of cattle manure generated as well as the use it was put to by the farmers. As a result of this work, we determined that the volume of cattle manure generated per cow and day varied between 50-55 litres, and that the manure was used on Asturian farms as a fertilizer (Marañón et al. 1998). Subsequently, characterisation of the manure was carried out on 7 farms (Castrillón et al. 1998). Two of these, corresponding to 75 and 25 cows, were chosen for the anaerobic treatment study.

Within the field of cattle manure treatment, the possible solutions/treatments may be diverse: agricultural use of the manure, which implies knowledge of the factors of usage and of the land where it is to be applied; phase separation; composting; aerobic and anaerobic treatments (Aburas et al. 1995; Boiran et al. 1996; Espona et al. 1995; Jungersen & Ahring 1994; Kanwar & Guleri 1994; Rulkens & Have 1994; Shyam & Sharma 1994; Wetterauer & Killorn 1996), etc.

1.2. Anaerobic digestion of manure

Anaerobic processes are some of the most interesting, since they simultaneously produce biogas, which is an energy source that can contribute to the self-sufficiency of the farm. A number of different countries use this kind of treatment, one of which is Denmark, where cattle manure is treated in centralised biogas plants (Danish Energy Agency 1995). The first large-scale centralised biogas plants were planned and built in the early 1980s. These process animal manure and to a lesser degree, organic waste; the latter must be free from environmental toxins and can be used on the land on the same footing as animal manure.

In Spain, different pig farms use this technique to remove organic matter and produce biogas (Flotats et al. 1997), but at present, anaerobic treatment has hardly been employed on cattle farms.

1.3. Objective

The aim of this work was to study the anaerobic treatment of bovine cattle manure. The manure used in this study was produced on two farms, one with 75 cows and the other, with 25 cows. Previously, a characterisation study was carried out of the cattle manure from Asturian farms, the main difference amongst which was the number of animals. In order to obtain steady-state operation data and to optimise COD removal and the production of biogas with lower hydraulic residence times, a continuous operation was planned. The upflow anaerobic sludge blanket (UASB) reactor was chosen since it has proven itself to be a highly efficient process, and has been applied to the treatment of a wide range of organic wastewaters with COD concentrations under a wide range of conditions.

2. Experimental

2.1. Reactors

The UASB reactors were constructed of transparent PVC (Figure 1). Each reactor consisted of two cylindrical sections, the lower one jacketed and separated from the upper one by a deflecting ring to facilitate phase separation. The upper part had a larger diameter and contained the gas collector, as well as outlets for the effluent, recycling and other uses. Other side-outlets for samples were arranged along the lower body. The volume of the reactors up to the triphasic separator was 8 and 9 litres, respectively.

2.2. Analytical methods

The parameters analysed in the liquid cattle manure were: COD, ammoniacal nitrogen, ($N\text{-}NH_4^+$), phosphate (PO_4^{3-}), total solids (TS), volatile total solids (VTS), volatile acidity (VA), total alkalinity (TA), gas volume, gas composition and metals. The standard methods were employed whenever applicable (Apha, 1989).

The metals were determined by atomic absorption. Measurements were carried out by means of a Perkin Elmer Mod. 3110 spectrophotometer.

The volume of gas produced was measured using a HI-TEC F101D thermal mass flow detector equipped with an electronic totaliser. The volumetric composition of the biogas was determined by means of a Geotechnical Instrument portable methanometer.

2.3. Starting up and operating mode

The previously sieved cattle manure used in this treatment came from a farm with 75 cows. The samples were kept under refrigeration after collection. Before introducing the manure into the reactors, it was conditioned by maintaining it in a closed recipient at a temperature of 37ºC, the pH being kept around 7 by means of the addition of hydrochloric acid and small amounts of methanol. Once a constant production of biogas was observed, the manure was introduced into the reactors until they were two thirds full. On newly detecting the production of biogas, the reactors were continuously fed with manure, using an initial hydraulic residence time (HRT) of 22.5 days in one and of 16 days in the other. The previously described parameters were determined in the manure used as feed for the reactor. At the same time, the effluent from the plant, as well as the biogas generated in it, were also characterised.

3. Results and discussion

3.1. Characterisation of manure

The results obtained in the characterisation of manure from 6 farms show the following differentials: on the first four farms with 17, 25, 35 and 75 cows, the COD varied between values of 52,000-45,000 mg O_2/l; on the fifth farm, with a large number of animals (350), not at all typical in Asturias, the COD was very high (around 74,000 mg O_2/l); while the other farm, characterised by an open storage tank, had a much lower COD, in the order of 11,000 mg O_2/l, due mainly to dilution caused by rainwater. The amount of N-NH_4^+ was always below 2,000 mg/l. Of the metals analysed (Fe, Cu, Ni, Zn, Cd, Pb), the major ones present were Fe, Zn and Cu. More detailed data can be found elsewhere (Castrillón et al. 1999).

Table 1 shows the average values of the composition of the filtered manure used in our work. The COD of the majority of the samples ranged between values of 33,000 and 56,000 mg O_2/l, with the exception of one sample which presented abnormally high values and which was used during a short period of time. The ammoniacal nitrogen content was high, but except for the HRT of 5.3 days, its values generally remained around 2,000 mgN-NH_4^+/l or less. These amounts did not perturb the smooth running of the anaerobic process (Flotats et al. 1997). The phosphate levels varied between 155.3 and 898. The pH value was, in general, greater than 7.

3.2. Performance of the UASB digesters

Digester 1 operated continuously for 348 days working with different HRTs (16, 10.6, 8.9, 7.3, 5.3). A higher HRT, 22.5, was employed in reactor 2 during a period of 67 days. The percentage of COD removed varied between 36.2 and 75.5% for a HRT of 5.3 and 22.5 days, respectively. Given the fact that for even a high HRT (22.5 days) the percentage of COD removed is around 75%, an anaerobically non-biodegradable organic fraction may possibly exist. The model proposed by Chen and Hashimoto (Chen & Hashimoto, 1980) allows us to determine the value of this fraction.

The percentage in volume of methane in the biogas varied between 64.4% and 73.7%. Table 2 summarises COD removals and the volume and composition of the biogas generated.

In anaerobic processes, the content of metals in the manure decreases due to precipitation as sulphides. This fact can be seen in Table 3.

3.3.Kinetic model

If the ratio S/So (concentrations of effluent and influent, expressed as COD) is plotted versus HRT (Fig. 2), a concordance for all points can be observed. The Chen and Hashimoto model was applied to the experimental data with the following results for the different parameters:

Kinetic constant, k = 1.31

Specific growth rate, μ_m= 0.358 day^{-1}

Refractory fraction, R = 0.11

The fraction refractory to biodegradation (R) was determined to be about 11%, which means that a fraction that is refractory to anaerobic treatment exists in cattle manure that is mainly made up of lignocellulosic material not digested by the animal.

4. Conclusion

Anaerobic treatment may be applied to the liquid cow manure studied, resulting in a high percentage of COD removal. However, the COD level of the effluent is still high. This fact, together with that of the high amounts of ammoniacal nitrogen present, imply the need to use this method in combination with others: aerobic and/or physico-chemical.

References

Aburas, R., Hammad, M., Abu-Reesh, I. Hiary, S. & Qousous, S., Construction and operation of a demonstration biogas plant, problems and prospects. *Bioresource Technology*, **53** (1995) 101-104.

APHA, AWWA, WPCF, *Standard Methods for the Examination of Water and Wastewater*, 17th, De. Public Health Association, Washington, D.C, 1989.

Barnett, G., Manure P fractionation, *Bioresource Technology*, **49** (1994) 149-155.

Boiran, B., Couton, Y. & Germon, J., Nitrification and denitrification of liquid lagoon piggery waste in a biofilm infiltration-percolation aerated system (BIPAS) reactor. *Bioresource Technology*, **55**, (1996) 63-77.

Castrillón, L., Marañón, E., Sastre, H., González, J. M., Generación de purines en Asturias: volumen y composición. VI Congreso de Ingeniería Ambiental PROMA' 99. Bilbao, 23-25 de febrero de 1999.

Chen, Y. & Hashimoto, A., Substrate utilization kinetic model for biological treatment processes. *Biotech. Bioeng*., **22** (1980) 2081-95.

Danish Energy Agency, Progress report on the economy of Centralized Biogas Plants, Copenhague, February (1995).

Espona, J., Turet, J., Viver, J., Aireación forzada del residuo de ganado porcino en régimen semicontinuo. *Tecnología del Agua*, **141**, (1995) 41-45.

Farrell, M.,Protecting city water on the farm. *Biocycle*, March, (1996) 42-48.

Flotats, X., Bonmatí, A., Campos, E., Antúnez, M. V Congreso de Ingeniería Ambiental PROMA' 97. Bilbao, 11 y 12 de Marzo de 1997.

Fundación “La Caixa”, Residuos ganaderos, Barcelona, (1993) 1-191.

Iglesias, L., *El estiércol y las prácticas agrarias respetuosas con el medio ambiente*, Ministerio de Agricultura Pesca y Alimentación, España, (1995) 1-24.

Jungersen, G. & Ahring, B., Anaerobic digestion of liquefied cow manure pretreated by catalytic liquefaction, *Wat. Sci. Tech*. **30**, 12 (1994) 385-394.

Kanwar, S. & Guleri, R., Performance evaluation of a family-size, rubber-balloon biogas plant under hilly conditions. *Bioresource Technology*. **50** (1994) 119-121.

Kanwar, S., Gupta, R. , Guleri, R. & Singh, S. , Performance evaluation of a 1 m^3 modified, fixed-dome Deenbandhu biogas plant under hilly conditions. *Bioresource Technology*, **50** (1994) 239-241.

Kirchmann, H. & Witter, E., Composition of fresh, aerobic and anaerobic farm animal dungs. *Bioresource Technology*, **40** (1992) 137-142.

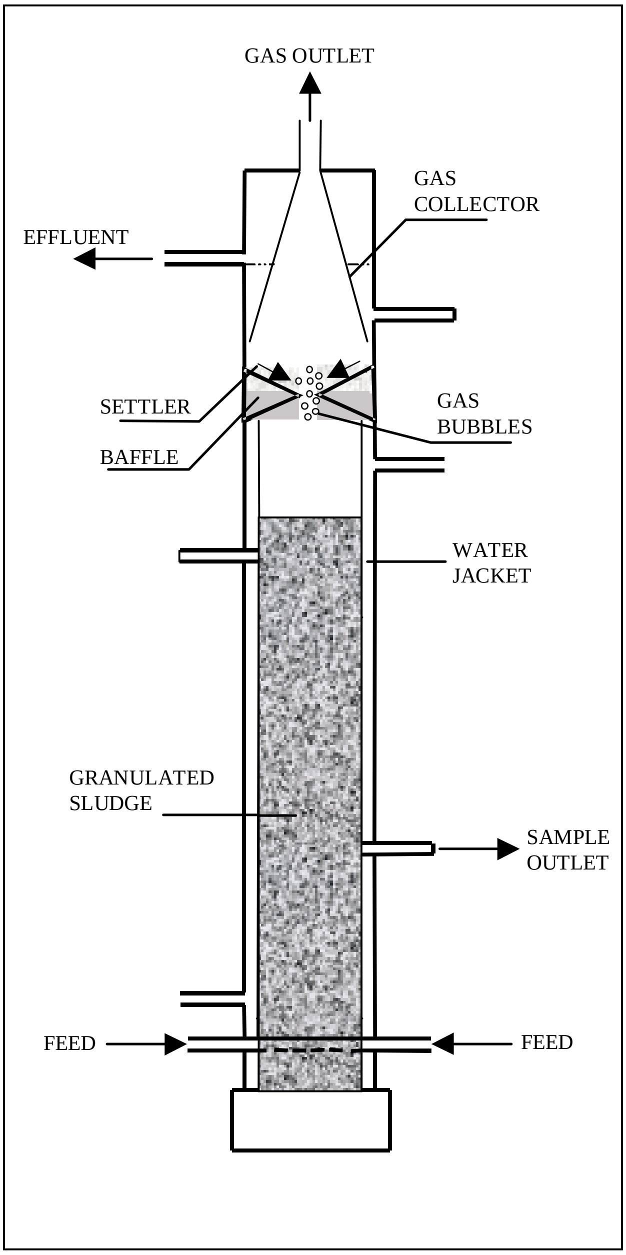
Marañón, E., Sastre, H., Castrillón, L., González, J.M., Pertierra, J., Berrueta, J. Generación de residuos de ganadería vacuna (purines) en Asturias. Problemática y tratamiento, Servicio de Publicaciones, Universidad de Oviedo, (1998) 1-202.

Proyecto Arcade, El Sector Agroalimentario en Asturias, Principado de Asturias, FADE, (1997) 1-323.

Rulkens, W. & Have, P. J. W. ten, Central processing of pig manure in the Netherlands. *Wat. Sci. Tech*., **30**,7 (1994) 157-165.

Shyam, M. & Sharma, P., Solid state anaerobic digestion of cattle dung and agro-residues in small-capacity field digesters, *Bioresource Technology*, **48** (1994) 203-207.

Wetterauer, D. & Killorn, R., Composting animal manure with municipal yard trimmings. *Biocycle*, October, (1996) 54-57.


GAS OUTLET
GAS
COLLECTOR
EFFLUENT
SETTLER
BAFFLE
GAS
BUBBLES
WATER
JACKET
GRANULATED
SLUDGE
SAMPLE
OUTLET
FEED
FEED

HRT		pH	COD	N-NH_4	VA
5.3	Average value	7.7	46,044	2,445	
	Ranges	6.7-8.3	38,688-52,889	1,036-4,060	
	Standard deviation	0.2	5,614	1,216	
7.3	Average value	7.3	37,988	1,226	2,736
	Ranges	6.9-7.7	32,638-49,418	924-1,324	2,736-4,378
	Standard deviation	0.24	4,805	219	767
8.9	Average value	7.2	43,619	1,106	3,285
	Ranges	6.6-7.8	32,638-56,656	560-1,708	1,872-4,296
	Standard deviation	0.4	9,108	478	694
10.6	Average value	7.9	45,502	2,100	
	Ranges	7.5-8.1	44,576-47,244	1,764-2,212	
	Standard deviation	0.3	1,250	224	
16	Average value	7.1	58,901	1,960	
	Ranges	7.0-7.4	44,741-82,284	1,260-2,212	
	Standard deviation	0.2	14,559	336	
22.5	Average value	7.4	46,913	1,375	3,604
	Ranges	6.9-7.9	35,928-56,656	784-1,764	2,856-4,296
	Standard deviation	0.3	9,031	417	588

All values in mg dm^{-3} except for pH

HRT	OLR	COD_{inf}	COD_{ef}	%COD	Vgas	$\%CH_4$
5.3	8.63	46,044	17,410	36.2	0.37	64.4
7.3	5.22	36,457	19,140	50.0	0.39	64.9
8.9	4.91	43,619	19,432	55.1	0.29	66.4
10.6	4.32	45,503	17,857	61.0	0.22	73.2
16	3.68	58,901	17,372	69.7	0.20	73.7
22.5	2.35	46,913	11,950	75.5		68.3

HRT, days.

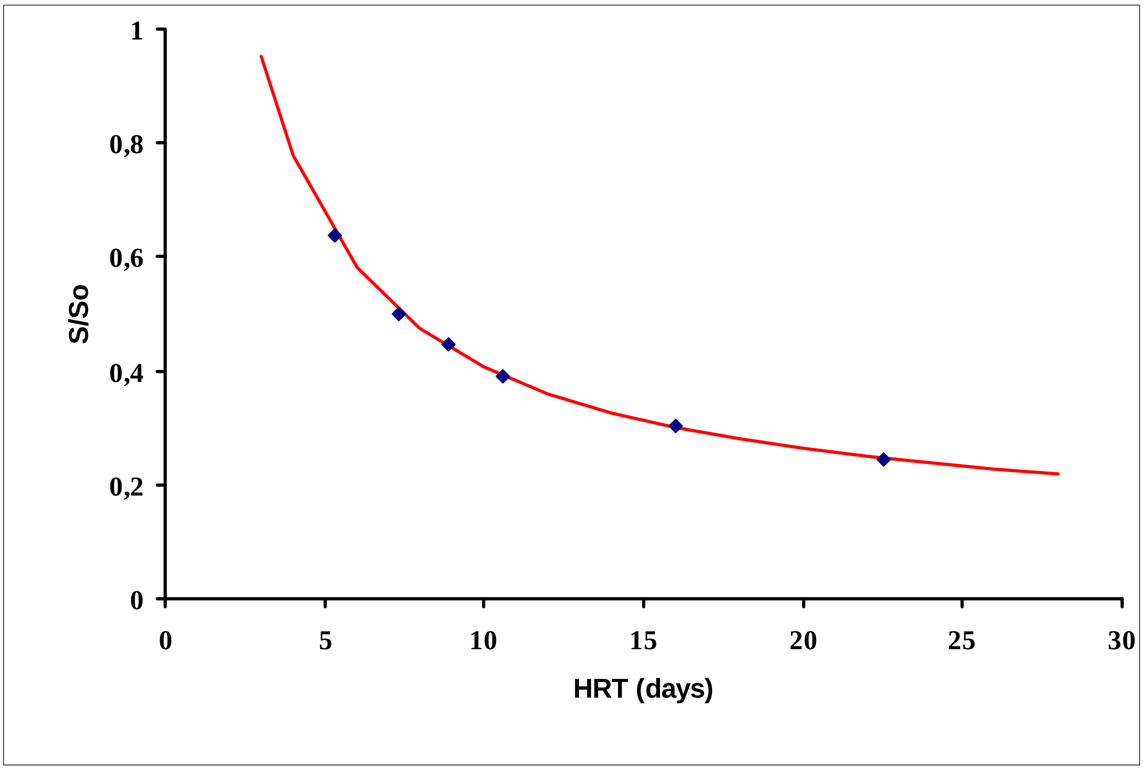
OLR, kg COD m^{-3} day^{-1}.

COD, mg dm^{-3}

V_{gas}, m^3 kg^{-1} COD removed

Metal	Fe	Zn	Cu	Ni	Pb	Cd	Cr
Influent	69.2	9.95	2.6	0.85	0.85	0.1	0.51
Effluent	58.8	7.4	2.5	0.7	0.6	0.07	0.36

All values in mg dm^{-3}



S/So
1
0,8
0,6
0,4
0,2
0
0
5
10
15
20
25
30
HRT (days)

COD	Chemical oxygen demand (mg dm^{-3})
HRT	Hydraulic residence time (days)
K	Kinetic constant
MSW	Municipal Solid Waste
OLR	Organic loading rate (kg m^{-3} day^{-1})
R	Refractory fraction
S	COD of the effluent
S_o	COD of the influent
TA	Total alkalinity (mg $CaCO_3$ dm^{-3})
UASB	Upflow anaerobic sludge blanket
VA	Volatile acidity (mg acetic acid dm^{-3})
V_{gas}	Gas volume (m^3 kg^{-1}COD removed)
μ_m	Specific growth rate (day^{-1})

Table 1 Characteristics of the cattle manure used in the experiment

Table 2. Percentage of COD removal. Quantity and composition of gas

Table 3. Metals: Averages values in the influent and effluent for HRT = 16 days

Figure 1. Diagram of the UASB reactors

Figure 2. Ratio COD effluent/influent versus HRT