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# Feeding approaches for biogas production from animal wastes and industrial effluents

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## Summary

Different feeding approaches were applied to a 5 l anaerobic digester in order to improve the biogas production. During operation, the reactor was fed with a mixture (9.7% w/v total solids (TS) and 7.6% w/v volatile solids (VS) in average) of pig manure with fish oil waste and waste from bentonite of edible oil filtration process, at different intervals of 24, 12 and 4 h at 15 days of hydraulic retention time. Production and quality of the biogas were practically constant at 183.7 ml (average) of biogas per gram of volatile solids available in the reactor per day, and the best biogas composition was 73.6% v/v $CH_4$ and 26.4% v/v $CO_2$.

## Introduction

Applications of anaerobic digestion have increased during the last twenty years. The process deals with the treatment of agricultural and industrial wastes of varying concentration and with production of energy sources.

The combined treatment of manure together with industrial and household solid waste and the associated biogas generation (Skajaa & Hannibal 1991) in biogas plants play an important role in decreasing pollution from the waste material treated.

This process generates in addition to biogas, digested sludge which is mainly utilized as fertilizer for plant production because the nutrients in the raw material remain in the mineralized sludge as accessible compounds (Hobson & Roberston 1977; Rodriguez Perez *et al.* 1998). As the digested solids are finer in size than the original solids, this is an advantage for easier pumping for fertilizer spreading.

Biogas, in turn, is a renewable energy source and a high quality fuel applicable for gas engines utilized for generating electric power and replacing the use of oil and coal, with all the environmental advantages this implies. This reduces the need for fossil fuel consumption which in turn reduces the emission of the greenhouse gas carbon dioxide.

The main environmental aims of the energy sector is the reduction in actual emissions of carbon dioxide ($CO_2$). Methane is also a greenhouse gas and has 10–20 times the deleterious effect of $CO_2$, and recently the importance of biogas plants on reduction of the uncontrolled release of methane from manure and organic wastes to the atmosphere has been emphasised, but the operating conditions are still being studied in order to improve the biogas production to obtain a constant biogas generation rate.

Organic compounds are converted to methane ($CH_4$) and carbon dioxide ($CO_2$) during anaerobic digestion by three bacterial groups (Verstraete *et al.* 1996) in which the first group is a complex of fermentative bacteria that hydrolyses polymers and ferments products to acetic and other organic acids, hydrogen and carbon dioxide. The hydrogen-producing bacteria are in the second group which convert propionate and higher fatty acids, produced by the first group, to acetate and hydrogen. Methane is generated by species of methanogenic bacteria from acetate and/or hydrogen and carbon dioxide produced by the other groups (Soubes 1994).

The feasibility of biosolids treatment has been established for mixtures of biosolids and wastes from agriculture and industry processed at centralized digestion plants (Cecchi *et al.* 1988; Rintala & Ahring 1994), but the particulate organic content of animal slurries must be solubilized because the rate of hydrolysis is a limiting factor (Pavlosthatis & Gosset 1986).

Carbohydrates, proteins and lipids are the main organic substrates in anaerobic digestion, which yield different amounts of biogas as shown in Table 1 (Ahring *et al.* 1991).

Bentonite-bound oil (BBO) with 94.4% total solids (TS) and 36.3% volatile solids (VS) (as % of TS), is a

*Table 1.* Substrate composition and gas yield from anaerobic digestion utilizing industrial wastes.

| Organic industrial waste | Composition | Organic content (%) | Methane yield ($m^3$/ton) |
|---|---|---|---|
| Bentonite-bound oil | 30–35% lipids, 5–10% other organic materials | 40–45 | 300–350 |
| Fish oil sludge | 30–50% lipids and other organic materials | 80–85 | 450–500 |
| Flotation sludge | 65–70% proteins, 35–30% lipids | 13–18 | 80–100 |

waste from edible oil production generated during cleanup and decolorization of vegetable oils employing the clay mineral bentonite (Ahring *et al.* 1991), which acts as an inert support in the digestion of swine wastewater (Duran Barrantes *et al.* 1998).

Fish oil waste (FOW) is a residue of the manufacturing of fish oil having 32.8% TS and 91.2% VS.

In an anaerobic digestion process using pig manure (5.6–10% of dry matter), the biogas yield amounts to ≈231 l of biogas per kg of volatile solids fed (Hobson & Roberston 1977).

An industrial plant for biogas production produces methane from those materials. Methane is used for heating and electricity production, under operational conditions that require a constant biogas generation because of the uninterrupted consumption required especially for electricity generation.

This research was conducted to improve the biogas production in a laboratory scale reactor treating pig manure together with fish oil waste and bentonite from edible oil filtration process.

## Materials and Methods

### *Reactor*

A 5-l cylindrical digester built in stainless steel and glass, provided with sampling ports on top and bottom for liquid and biogas was employed for the experiments. Continuously stirred at 30 °C in a water bath, the reactor was hand-fed at different intervals of 24, 12 and 4 h, at 15 days of hydraulic retention time.

### *Seeding*

Three litres of digested sludge effluent (7.8% TS, 74.3% VS) from a full scale anaerobic reactor (150 $m^3$) treating pig manure at Sindrup Biogas Plant (Denmark) was the only seed material employed for all experiments.

### *Feeding*

The slurry fed contained 97% v/v of pig manure, 2% v/v of fish oil waste and 1% v/v of bentonite-bound oil, resulting in a final concentration of 9.7% TS and 75.8% VS (on average). The reactor was fed with 2 l of the feeding slurry and operated initially in batch conditions during 15 h.

During stable operation the reactor was fed once (330 ml), twice (165 ml), or four times during the day (82.5 ml) with the same volume removed of the 5-l digester.

### *Analytical methods*

Temperature, gas production and composition, total solids (TS) and volatile solids (VS) content were determined daily. Gas volume was measured in an inverted graduated flask, equipped with a numerical counter.

Methane, carbon dioxide and hydrogen sulphide were determined by gas chromatography on a 5 × 1200 mm column (70 °C) filled with Chromosorb 107 using a Shimadzu GC-14A CR-R4A gas chromatograph with TCD and PID detector (at 170 °C) employing Helium as carrier (30 ml/min).

Volatile fatty acids (VFA) were determined by esterification of carboxylic acid present and determination of the esters by the colorimetric ferric hydroxamate reaction using a HACH DR/2000 spectrophotometer at 495 nm (HACH & Co., Loveland, Colorado, USA). Total and volatile solids were determined in a well mixed sample to constant weight, according to the procedure described in the previous work (Francese *et al.* 1998).

### *Biogas efficiency*

The gas generation was measured with respect to the amount of volatile solids available inside the reactor ($VS_{available}$) and the efficiency was calculated as follows:

$$\text{Biogas efficiency} = \text{ml biogas/day/g } VS_{available}/\text{day},$$

where $VS_{available}$ is the total content of volatile solids available for degradation calculated as the amount of solids that still remain in the reactor plus the new solids fed in each feeding.

## Results and Discussions

The behaviour at 30 °C of the reactor was analysed during 192 h after inoculation and filled to 5 l with the slurry (7.4% TS and 73.7% VS) containing pig manure, fish oil waste, and bentonite-bound oil. After 15 h in batch mode the biogas collected was 8.8 l.

330 ml of the reactor content was removed and the same volume of slurry was fed through the top of the reactor in the first feeding. The total content of volatile solids inside the reactor after the feeding was 98.2 g $VS_{available}$/day, the biogas accumulated was 14.1 l/day

and the biogas composition was between 73.6 to 59.5% v/v of $CH_4$, 26.3 to 40.5% v/v of $CO_2$ and 0.35 to 0.19% v/v of $H_2S$.

Figure 1 shows the evolution of biogas production. During this period the higher content of $CH_4$ in biogas was (73.6% v/v).

330 ml of slurry was replaced at the same time during the following three days, which meant an amount of 117, 97.2 and 100.8 g $VS_{available}$/day respectively inside the reactor which produced 20.0, 16.7 and 21.8 l of biogas per day. Biogas composition reached between 72.1 to 53.0% v/v for methane content, 46.9 to 27.8% v/v for carbon dioxide and 0.43 to 0.19% v/v for hydrogen sulphide, as shown in Table 2.

During the following two days, the reactor was fed every 12 h with 165 ml of the slurry causing a load of 97.4 and 60.6 g $VS_{available}$/day respectively to the reactor, which were partially converted into biogas. Gas composition reached a maximum of 73.6% v/v $CH_4$ and a minimum of 26.4% v/v $CO_2$. The lowest amount of $H_2S$ registered was 0.10% v/v, and the total gas generated per day during this period reached a maximum of 19.8 l/day.

Four feeds of 82.5 ml every 4 h were done in the operation day seven, which meant a total content of 115.1 g $VS_{available}$/day inside the reactor and the biogas accumulated was 15 l of biogas during this 24-h period. The biogas obtained was of good quality but its $CH_4$ content was a little lower than that of the previous approach. The biogas efficiencies of the different approaches performed were between 130.9 to 248.9 ml biogas/g $VS_{available}$ as indicated in Table 3.

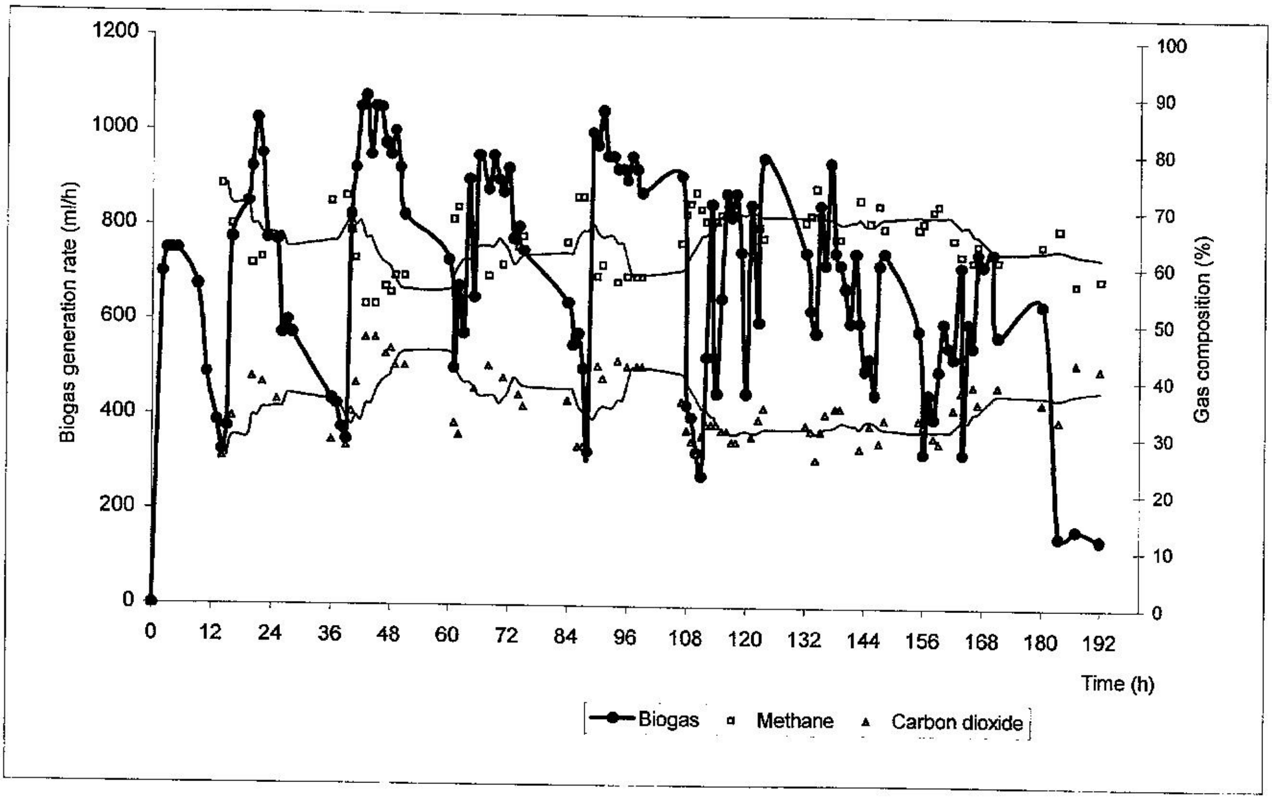


*Figure 1.* Biogas composition of a 5-l continuously stirred digester fed with pig manure, fish oil waste, and bentonite bound oil, operated at 30 °C.

*Table 2.* Data from operation of 5-l anaerobic stirred reactor treating animal together with industrial wastes.

| Operative time (day) | Feeding (ml/day) | Solids content in feeding | | Biogas production (ml/day) | Biogas[1] (% v/v) | | | Solids content in effluent (%w/v) | |
|---|---|---|---|---|---|---|---|---|---|
| | | TS (%w/v) | VS (%w/v) | | Composition $CH_4$ | Composition $CO_2$ | Composition $H_2S$ | TS | VS |
| 1 | 1 × 330 | 7.37 | 73.74 | 14,100 | 59.5–73.6 | 26.3–40.5 | 0.21–0.30 | 3.59 | 54.71 |
| 2 | 1 × 330 | 13.83 | 78.25 | 20,025 | 53.0–70.3 | 29.6–46.9 | 0.36–0.40 | 3.84 | 60.95 |
| 3 | 1 × 330 | 7.30 | 78.60 | 16,675 | 58.4–72.1 | 27.8–41.5 | 0.19–0.43 | 3.68 | 52.85 |
| 4 | 1 × 330 | 13.42 | 78.83 | 21,763 | 57.7–71.3 | 28.7–42.0 | 0.22–0.41 | 3.63 | 55.58 |
| 5 | 2 × 165 | 6.40 | 71.96 | 19,875 | 67.7–73.6 | 26.4–32.2 | 0.10–0.36 | 4.12 | 55.94 |
| 6 | 2 × 165 | 6.40 | 71.96 | 15,025 | 66.6–73.6 | 26.4–34.8 | 0.12–0.35 | 4.12 | 55.94 |
| 7 | 4 × 82.5 | 9.75 | 73.49 | 15,075 | 61.2–71.0 | 29.0–38.8 | 0.16–0.31 | 4.17 | 58.37 |

[1] Maximum and minimum.

*Table 3.* Efficiencies of anaerobic digestion.

| Operative time (day) | Biogas efficiency (ml biogas/ml reactor/day) | $VS_{available}$ (g/day) | Biogas efficiency (ml biogas/ g $VS_{available}$) |
|---|---|---|---|
| 1 | 2.82 | 98.2 | 143.6 |
| 2 | 4.02 | 117.0 | 171.1 |
| 3 | 3.34 | 97.2 | 171.5 |
| 4 | 4.36 | 100.8 | 215.7 |
| 5 | 3.98 | 97.4 | 204 |
| 6 | 3.00 | 60.6 | 248.9 |
| 7 | 3.01 | 115.1 | 130.9 |

## Conclusions

The anaerobic digestion of pig manure together with fish oil waste and the waste from bentonite of edible oil filtration process, is a feasible process and the addition of those industrial wastes to the animal waste improves the digestion process by increasing the net daily biogas production per cubic metre of digester compared to the sole utilization of animal waste, and represents a fourfold increase as compared to pig manure (Hobson 1977), where it was possible to generate one volume of gas per volume of reactor/day. The experiment presented here results in a gas with a composition of 65% v/v $CH_4$ in average.

The system operation was more stable when fed twice in a 24-h period and gave maximum gas production as compared with multiple feedings. In this last condition, the digester does not produce more biogas per hour. The process suffers from a great deal of interferences during this operation, that alter the hydrolysis step resulting in a probable inhibition of methanogenesis.

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