A comparative examination of the start-up of a mesophilic and a thermophilic anaerobic filter treating a synthetic coffee waste

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Abstract

Two anaerobic filters were operated at 37°C and 55°C with a synthetic soluble coffee wastewater to compare the performances of mesophilic and thermophilic digestors. After the initial start-up phase, they were operated at organic loading rates of 4 and 6 kg COD $m^{-3}d^{-1}$ with a fixed hydraulic retention time of 24 hours. The results showed that, in terms of COD removal, gas production and methane yield, the mesophilic filter produced the better performance.

Key words: Anaerobic filters, coffee wastewater, mesophilic digestion, thermophilic digestion.

Un análisis comparativo de la puesta en marcha de dos filtros anaeróbicos, mesofílico y termofílico para tratar un agua residual de café

Resumen

Dos filtros anaeróbicos fueron operados a 37°C y 55°C con un agua residual sintética de café, para comparar el comportamiento de los digestores mesofílicos y termofílicos. Después de la fase inicial de puesta en marcha, los filtros fueron operados a tasas de carga orgánicas de 4 y 6 kg de DQO $m^{-3}d^{-1}$ con un tiempo de retención hidráulico fijo de 24 horas. Los resultados presentan que en términos de remoción de DQO, producción de gas y rendimiento de metano, el filtro mesofílico demostró el mejor comportamiento.

Palabras claves: Filtros anaeróbicos, aguas residuales de café, digestión mesofílica, digestión termofílica.

Introduction

High rate anaerobic reactors, which utilise an immobilised biomass, are now a regularly considered option for the treatment of high strength industrial wastewaters. However, despite there being many reported instances of other types of waste being treated, the majority of the commercial anaerobic digesters are used for the treatment of wastewaters from the food industry. These are mainly filters and upflow sludge blanket reactors.

In the United Kingdom, the annual production of instant coffee is around 50-60 x 10^3 tonnes and, will generate a significant polluting load. The composition of these wastewaters depends on the type of process used to remove the spent coffee grounds from the wastewater. For example, the COD (Chemical Oxigen Demand) can range from 4 g ℓ^{-1} to 60 g ℓ^{-1}. In other words, these wastes have considerable potential for being treated anaerobically. However, there are few reports about the anaerobic treatment of liquid wastes resulting from coffee processing. Calzada *et al.* [1] have described the production of biogas from coffee pulp juice and Hajipakkos [2] has discussed the use of an upflow sludge blanket (UASB) to treat coffee wastes on a full-scale. The UASB process is also being used elsewhere to treat flows of 654 $m^3 d^{-1}$ and 2000 $m^3 d^{-1}$ from the production of instant coffee (Paques BV, personal communication). In all these cases, the operational temperature of the digesters was in the mesophilic range. However, some of the waste streams are produced at higher temperatures and could be considered for termophilic treatment.

Thermophilic anaerobic digestion has been studied, with both laboratory and full-scale reactors, using a variety of wastewaters; for example, palm oil mill wastes [3], kraft liquors [4] and pharmaceutical wastewater [5]. However, it is known that thermophilic methanogens can be more sensitive to toxins than their mesophilic equivalents [6] and that the morphology of anaerobic thermophiles is slightly different from mesophilic species [7]. Although the use of thermophilic digestion does offer the advantage of greater reaction rates, fixed film thermophilic digesters have been reported to exhibit problems associated with attachement to the packing material [8], which obviously will affect the performance.

Reports on the treatability of wastes from coffee processing are conflicting. Lane [9] has reported that the mesophilic digestion of spent coffee grounds is inhibited by some component of the waste and that solutions of instant coffee had a similar effect. However, Kida and Sonada [1] have shown that, although a single stage thermophilic (53°C) digestion of coffee grounds was not stable, a two stage process did produce a stable and repeatable performance. This paper, therefore, compares the performances of a mesophilic and a thermophilic filter during the initial 23 weeks of treatment.

Table 1

Reactor characteristics

	Mesophilic	Termophilic
Internal diameter (cm)	7.1	7.1
Overall liquid height (cm)	57.00	55.83
Void space (%)	65	65
Empty volume (l)	2.25	2.20
Working volume (l)	1.63	1.58
Active volume (l)	1.14	1.14
Bottom volume (l)	0.15	0.21
Top volume (l)	0.34	0.23

Methodology

The details of the two filters are given in Table 1. The thermophilic digester, which was 57 cm in height with a diameter of 7.1 cm, was made out of glass. The mesophilic filter (56 cm x 7.1 cm diameter) was made out of PVC. In both cases, the temperature (either 37°C or 55°C) was maintained by the circulation of water through an external jacket and the packing material was ceramic Rasching rings (13.2 mm x 13.2 mm external diameter). A distribution plate, having an array of 5 mm holes, was located 100 mm from the bottom of each reactor, both to ensure that there was an even distribution of the feed and to support the media. In Table 1, the active volume refers to the interstitial volume within the bed itself and the working volume to the overall liquid volume within the reactor. In calculating loading rates and hydraulic retention times, the latter volume was used. The biogas was collected by the downward displacement of 0.05 M H_2SO_4 and its measured volume was corrected to STP (0°C and 1 atmosphere).

A synthetic coffee wastewater, based on soluble, instant coffee, was used as the feed. The nitrogen and phosphorus concentrations were

Table 2

Composition of the feed

Constituent	Concentration in feed
Coffee	3.11 - 5.00 $g\,l^{-1}$
NH_4HCO_3	1.13 - 1.69 $g\,l^{-1}$
Lab Lemco	0.50 $g\,l^{-1}$
$NaHCO_3$	0.00 - 2.00 $g\,l^{-1}$
KH_2PO_4	0.13 - 0.17 $g\,l^{-1}$
K_2HPO_4	0.10 - 0.13 $g\,l^{-1}$
$(NH_4)_2SO_4$	0.13 $g\,l^{-1}$
$MgCl_2$	0.085 $g\,l^{-1}$
$CaCl_2$	0.04 $g\,l^{-1}$
$FeCl_2.6H_2O$	0.64 $mg\,l^{-1}$
$NiSO_4.6H_2O$	500 $\mu g\,l^{-1}$
$MnCl_2.4H_2O$	500 $\mu g\,l^{-1}$
$ZnSO_4.7H_2O$	500 $\mu g\,l^{-1}$
H_3BO_3	100 $\mu g\,l^{-1}$
$CoCl_2.6H_2O$	50 $\mu g\,l^{-1}$
$CuSO_4.5H_2O$	5 $\mu g\,l^{-1}$
$H_3PO_4.12MoO.24H_2O$	40 $\mu g\,l^{-1}$

adjusted, as the COD was increased, so that a COD:N:P ratio of 100:5:1 was maintained. The composition of this feed is given in Table 2. The substrate was fed to the digesters at a rate of 1.6 ℓ day^{-1} by peristaltic pumps (Watson Marlow Ltd., Model 100).

Each of the reactors was started-up in an identical way. A sludge (30% of the working volume), which had been acclimatised to the reactor temperature, was added to each digester, which was then filled with substrate (COD = 1000 mg ℓ^{-1}). After 24 hours, this mixture was pumped on a recirculation loop for a further 48 hours. The recycle phase was then stopped and the digesters were fed continuously using a flow rate of 1.6 ℓ day^{-1} (i.e. a hydraulic retention time of 24 hours) and a substrate COD of 2000 mg ℓ^{-1}.The strength of the waste further increased, on Day 6, to 4000 mg ℓ^{-1}. This organic loading (4kg COD m^{-3} d^{-1}) was maintained until Day 110 when it was increased to 6 kg COD m^{-3} d^{-1}. No further increase in loading rate were made.

The effluent from each reactor was monitored regularly by measuring its pH value and the COD concentration. The latter parameter was measured by the standard dichromate method [11].The composition of the biogas was measured with a Perkin Elmer F30 gas chromatograph using a 2 m column, maintained at 60°C, packed with Unibeads A (80 - 100 mesh) (Alltech, Carnforth, Lancashire). Helium was used as the carrier gas at a flow rate of 10 mℓ min^{-1}. The sample (0.5 mℓ) was injected at 100°C and the detector temperature was also 100°C.

Results and discussion

The data presented in Figure 1 show the way in which the COD removal varied over the test period. The main points of note are that the initial period for reactor stabilisation was about two weeks, that there was a significant drop in COD removal, initially, when the load was increased from 4 to 6 kg COD m^{-3} d^{-1} and that the performance of the mesophilic filter was better than that of the thermophilic reactor. Figure 2, in which the gas production data are given, shows a similar pattern, although the time to reach "steady state" (in terms of this parameter) was slightly longer. However, both digesters reacted in a similar way to the increase in organic loading rate and, once again, the mesophilic reactor showed the better performance. The differences between the two reactors is shown even more markedly in Figure 3 in which the variations in the methane content of the biogas are given. These are most pronounced at the lower of the two loading rates.

The data in these three figures can be used to derive specific gas yields (m^3 CH_4 kg^{-1} COD removed). This is the best way of specifying digester performance and, in addition, it enables

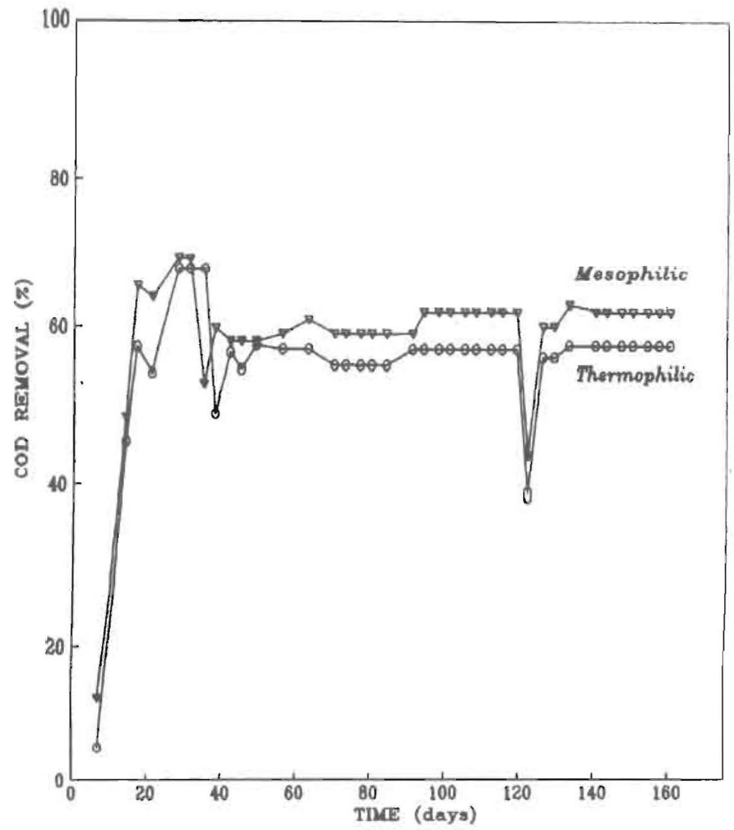

Figure 1. COD removal data for the thermophilic and mesophilic reactors.

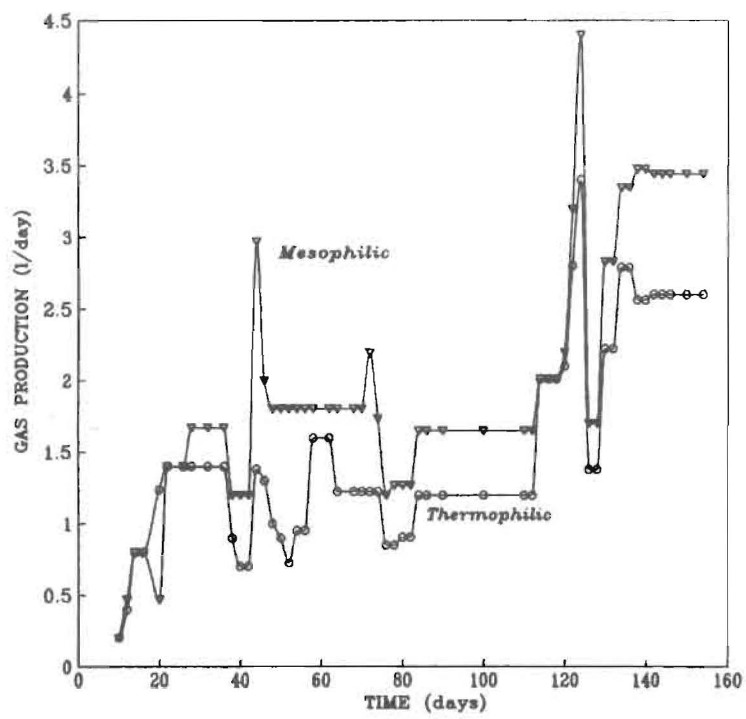

Figure 2. Gas production data for the thermophilic and mesophilic reactors.

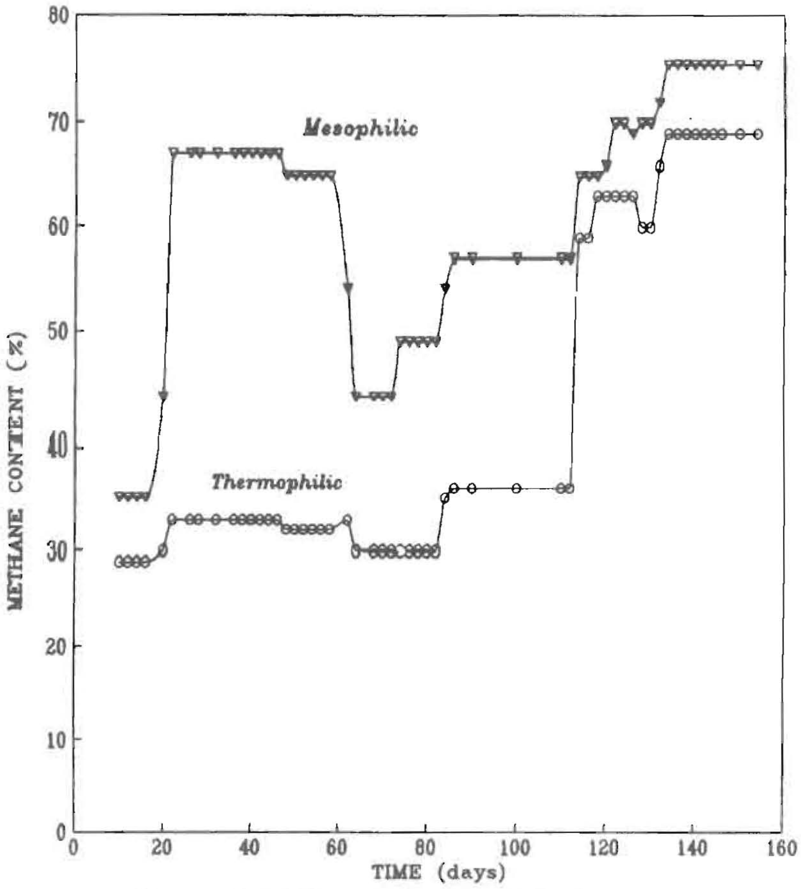

Figure 3. Methane content of the biogas.

realistic comparisons to be made with the results reported by previous workers has been made. To the authors knowledge, no previous study into the thermophilic treatment of coffee wastes has been made. However, there are some data for mesophilic treatment using the UASB process [2]; (Paques BV, personal communication). The data from these two studies, together with the results of this current work are shown in Figure 4 as the specific gas yields in relation to the applied organic loading rate (kg COD m^{-3} d^{-1}). It is obviously unrealistic to attempt any statistical analysis on such limited data but there does appear to be a trend, which should be noted, at least for the mesophilic digesters. Figure 4 also highlights the differences between the thermophilic and the mesophilic temperatures.

This type of difference has also been described by Hamdy *et al.* [5] who have reported that, in the treatment of pharmaceutical wastes, a mesophilic filter performed better than one operating in the thermophilic range. However, these workers showed that there was a further difference in that as the organic load was increased form 0.53 to 1.49 kg COD m^{-3} d^{-1}, although the COD removal by the mesophilic reactor increased, the thermophilic digester removed a lower percentage of the applied COD. This was a different pattern of behaviour from that developed in this current study.

It is also different from other comparisons that have been made. Yang *et al.* [12], using a wastewater based on glucose and corn-steep liquor, have demonstrated that a thermophilic fixed film digester was "as efficient and as stable as the mesophilic process". Ugurlu and Forster [13], comparing the two types of treatment for an ice cream wastewater, showed that the gas yields (expressed as m^3 CH_4 m^{-3} d^{-1}) from a thermophilic filter were, for any organic loading rate, greater than from a mesophilic filter. However, it must be recognised that both pharma-

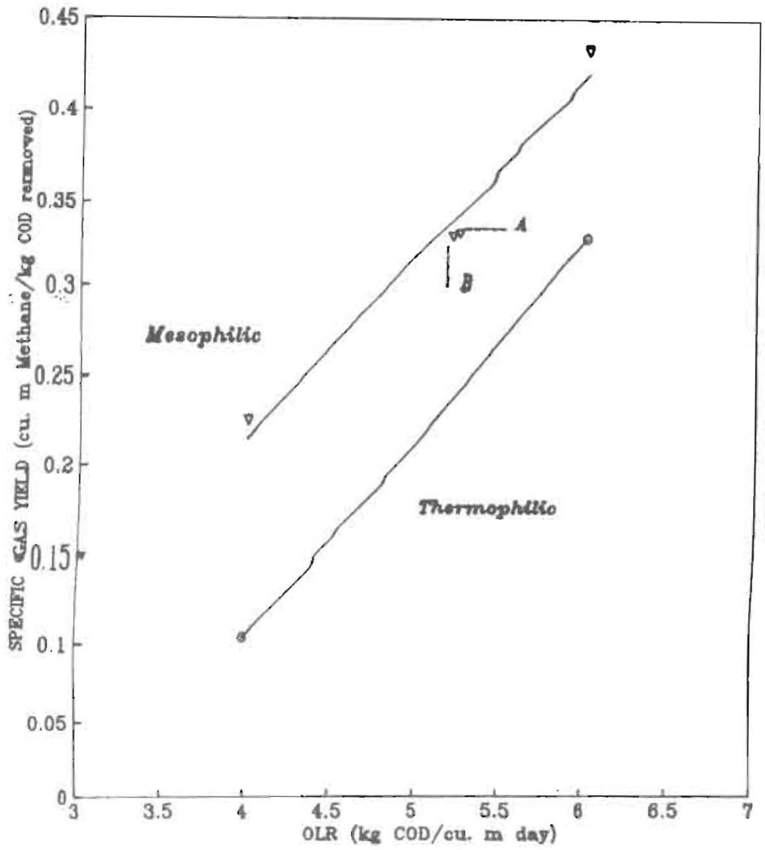

Figure 4. The relationship between the biogas yield and the organic loading rate for digesters treating coffee wastes.

A: 880 m^3 UASB (Hajipakkos, 1992)

B: 435 m^3 UASB (Paques BV)

ceutical wastes and the coffee wastewaters may contain compounds that have a potential for inhibition. It is also known that a thermophilic anaerobic biomas is more susceptible to the action of toxic or inhibitory material than mesophilic sludge, although this susceptibility appears to be less marked for organic compounds when compared with heavy metal ions [14]. The results presented in this paper do show that digestion in the thermophilic range does not achieve such a good conversion of COD to methane. However, the precise nature of the inhibitory action is yet to be determined as is the material responsible.

Conclusions

The results of this study show that the synthetic soluble coffee waste can be treated successfully by mesophilic anaerobic digestion and that the performances are very comparable with those reported previously for full-scale digestors. It was also shown that thermophilic digestion was not such a successful treatment process, whatever criteria were used to make this judgement. Taken in conjunction with data reported previously for the treatment of pharmaceutical wastes, the results suggest that there are components in the synthetic coffee waste, possibly phenolic material, which are producing an element of inhibition at the higher temperature. Hence, there is a need to determine both the nature of these components and the point at which they act (i.e. on the acidogenic or the methanogenic phase) if thermophilic digestion is to be contemplated on an industrial scale.

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