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EXPERIMENTAL COMPARISON OF TWO TYPES OF AVANCED ANAEROBIC REACTORS.

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ABSTRACT.

The Upflow Anaerobic Sludge Blanket (UASB) and the fixed film reactors (F.F.) had been compared at the laboratory scale, using a synthetic wastewater as effluent containing acetic and propionic acids as substrates. The UASB reactor developed an highly active biomass: 9.3 Kg COD/Kg VSS.d for substrate consumption and 3.46 l CH_4/g VSS for methane production. Such specific rates indicate the reactor was operated near saturation with a high COD removal efficiency (94%). The determination of the VSS content of the fixed film reactor allows to calculate lower rates. Both reactors were able to treat efficiently this type of effluent up to volumetric organic loads of 15 Kg COD/m^3.d. The scaling up of both reactors will have to look carefully for an appropriate liquid distribution at the reactor bottom.

INTRODUCTION.

The advances performed in the field of anaerobic digestion over the last decade, has transformed this technique to treat urban and industrial waste waters, into an attractive alternative (Speece, 1983).

The number of units to process anaerobically industrial waste waters has increased quickly in Europe (Hulsoff Pol et al, 1988; Segura 1983). In Brazil (Vieira and Souza,1986) and Colombia it is intented to applied the avanced anaerobic reactors to the treatment of urban waste waters. In Mexico, in spite of the numerous advantages of these process, there are very few experimental works were done with them (Mejia and Magaña, 1986; Monroy and Noyola, 1986; Young et al., 1987).

This work presents the experimental results obtained at laboratory scale, with the following anaerobic reactors: upflow sludge anaerobic blanket (UASB) digestor and tubular fixed film (F.F) reactor. These reactors will be fed with a synthetic waste water. These process fulfil the requirements for being applied at Mexico, and they have proved to be operative in others developing countries. However, in spite of their industrial development, it is still necessary to perform intensive research efforts, to understand the complexity of the microbial relationship which together with reactor design determine their efficiency. Particularly, the production and the control of well adapted anaerobic inoculum is still a major problem, mainly in relation with the production of granular sludge and degradation of recalcitrant compounds.

This study is a part of a larger research program, which tries to define an appropriate technology, which will be used to face up to the problem of water pollution in Mexico.

MATERIAL AND METHODS.

EXPERIMENTAL SET-UP.

The experiment had been performed using two reactors of each type (UASB, F.F.) named: UASB 1 and 2, F.F. 1 and 2 operated at 33'C. The reactors were made with acrilic columns of 9.6 cm of diameter and 1 m of height.

The UASB reactors (UASB 1 and UASB 2) (Fig. 1a) have an useful volume of 4.5 lt. The fixed film reactors (F.F 1 and F.F 2) (Fig. 1b) were packed with PVC tubing (1/2'diameter) and contained each 21 tubings of 67 cm of height, with a relationship area/volume of 221 m^2/m^3. The F.F. reactors had an useful volume of 4.75 lt. The reactors had been fed using peristaltic pumps and a synthetic waste water containing acetate and propionate as substrates (Table 1). The gas was collected in columns filled with an acidified brine .

START-UP.

Two different inocula were used: a fresh cow manure and an activated sludge from a secondary settler of an aerobic urban waste

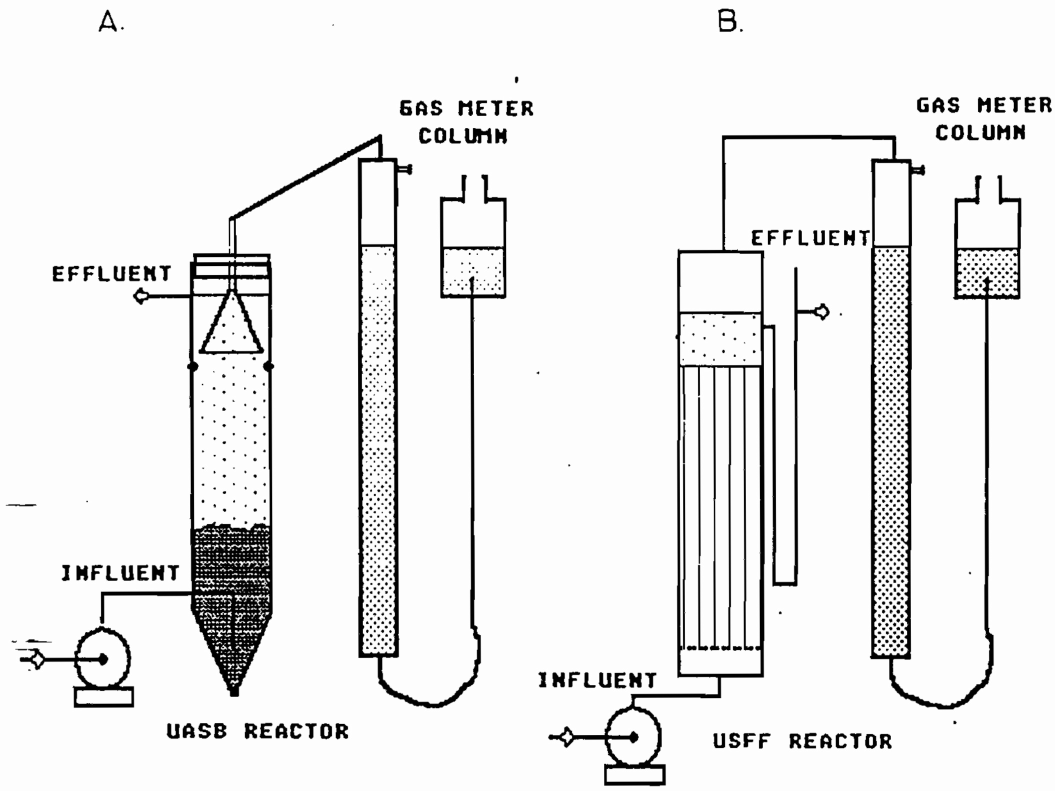

FIG. 1 SCHEMATIC DIAGRAM OF THE LABORATORY REACTORS

water treatment plant. The fresh cow manure was used to inoculate UASB 1 and F.F 1, the activated sludge was used for UASB 2 and F.F. 2. Both inocula were adapted anaerobically: the fresh cow manure was allowed to stay one month in the Khan et al. (1979) medium, and the activated sludge was processed according to Arias and Noyola (1987). In both case 2 l of sieved inoculum (mesh. 0.96 mm) and 2 l of synthetic medium (Table 1) were introduced in the reactors and recirculated 10 days. At the end, the F.F. reactors were purged to remove the sludge in excess.

Table 1. Composition of the synthetic waste water used to feed the anaerobic reactors.

COMPOUNDS	CONCENTRATION
CH_3COONa	5 g/l
CH_3CH_2COOH	1 ml/l
NH_4Cl	660 mg/l
$NaHCO_3$	600 mg/l
$(NH_4)_2SO_4$	250 mg/l
K_2HPO_4	130 mg/l
KH_2PO_4	100 mg/l
$CaCl_2.2H_2O$	200 mg/l
$MgCl_2.6H_2O$	100 mg/l
$FeSO_4.7H_2O$	14 mg/l
Mo, Mn, Cu, Zn, Al, Ni, Co	
tap water	
COD	5 to 5.2 g/l

OPERATION OF THE REACTORS.

Various hydraulic retention times (HRT) were applied from 72 h to 2 h. The following parameters were determined: pH, chemical oxygen demand (COD), gas production and composition, and the sludge volumetric index (svi) according to the manual of Standard Methods (APHA, 1980). The gas was analized by gas chromatography. The real HRT was determinated by a tracers technique (Levenspiel, 1972) using bromocresol green and spectrophotometry (617 nm) (Jimenez et al., 1988).

RESULTS.

The start-up of the four reactors was iniciated at high HRT, which was decreased after reaching each time the steady state. The steady state was considered established when the parameters kept constant over at least 5 TRH.

The reactors UASB 1 and F.F. 1, inoculated with fresh cow manure, did not present methanogenic activity during the first three months of continuous feeding. For that reason a very small amount of sucrose (500 mg/l) was added to the synthetic waste water, in order to allow facultative anaerobes to use the dissolved oxygen, and then to reduce the redox potential in the reactor. This modification resulted in a rapid increased in the methane production, reaching a stable level in one month for UASB 1 and two months for F.F.1 (Fig. 2). UASB 2 and

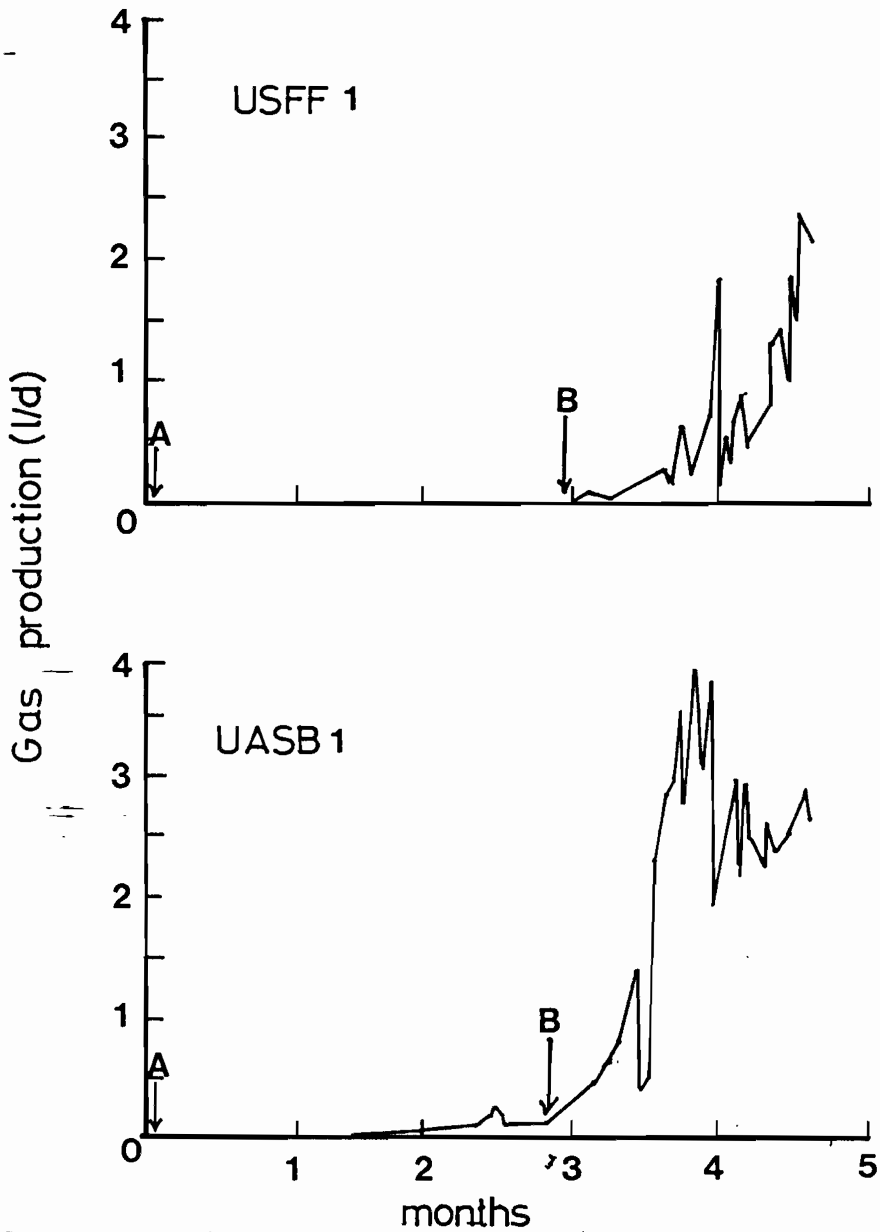

Fig. 2. Daily gas production during the first five months of experimentation. A: start up, B: Sucrose addition.

F.F.2 were inoculated with adapted activated sludge, and fed since the beginning of the start-up with the mixture of VFA and sucrose. Biogas production started immediately.

Fig. 3 shows the relationship between HRT and the efficiency of COD removal for the 4 reactors. The curves present the typical profile for this type of work, with a good clumping of the experimental data. The efficiency of COD removal keeps constant (94%) over a range of COD values, but at HRT below 12 hours, the efficiency rapidly decreased to get a value of 52% at a HRT of 2 hours. Furthermore, in terms of loading rates, the efficiency of COD removal decreases markedly for organic loading rates superior to 15 kg COD/m^3.d, at 60 kg COD/m^3.d the efficiency decreases to 52% (Fig. 4).

The pH at the inlet of the reactors was 6.5, and at the outlet was of 8.2 for high HRT and 7.8 for HRT below 12 hours. This relatively low pH of the feed did not affect the efficiency of the process.

The maximum gas production per volume of reactor was 18.3 l/l.d (at standard conditions) and was reached for the reactor F.F. 1 at a organic space loading rate of 60 kg COD/m^3.d. The average methane content was 52%.

The amount of sludge and the volumetric index (svi), were determined for UASB 2. The reactor contained 9.73 g of TSS with a VSS content of 46% , the volumetric index was 37 ml/g. With a volume of 360 ml the sludge represented 8% of the reactor total volume.

At the end of this study, the real HRT were determined in both fixed film reactors (F.F. 1, F.F. 2) by using tracers. The reactors were operated at a theoritical HRT (space time) of 8.7 h. The results were ajusted to a hydraulic model: J reactors in series with dead-space and J reactors in series with dead-space and hydraulic short-circuit. From the experimental and the ajusted curves (Fig.5), it is shown that the real HRT were markedly lower than the theoretical values, which means there is a high percentage of dead spaces. From the hydraulic model which fits better the experimental data for F.F. 2, a great part of the reactor can be considered as afected by a short-circuit. At the end of the experimental work, in order to determine the displaced volume by the accumulated biofilm, the fixed film reactors were emptied. The final liquid volumes obtained in F.F. 1 and F.F. 2 were 3.35 l and 2.5 l respectively. At the beginning of the experiment, the useful volume was 4.75 l for each reactor. For both reactors, the biofilm can be considered as a dead space. For F.F. 2, the decrease of nearly 50% of the useful volume can explain the important short-circuit.

DISCUSSION.

START-UP.

The methanogenic bacteria did not show any activity during the first 3 months, probably because the redox potential was not appropriate: no reducing agent was used in the feed. The addition of

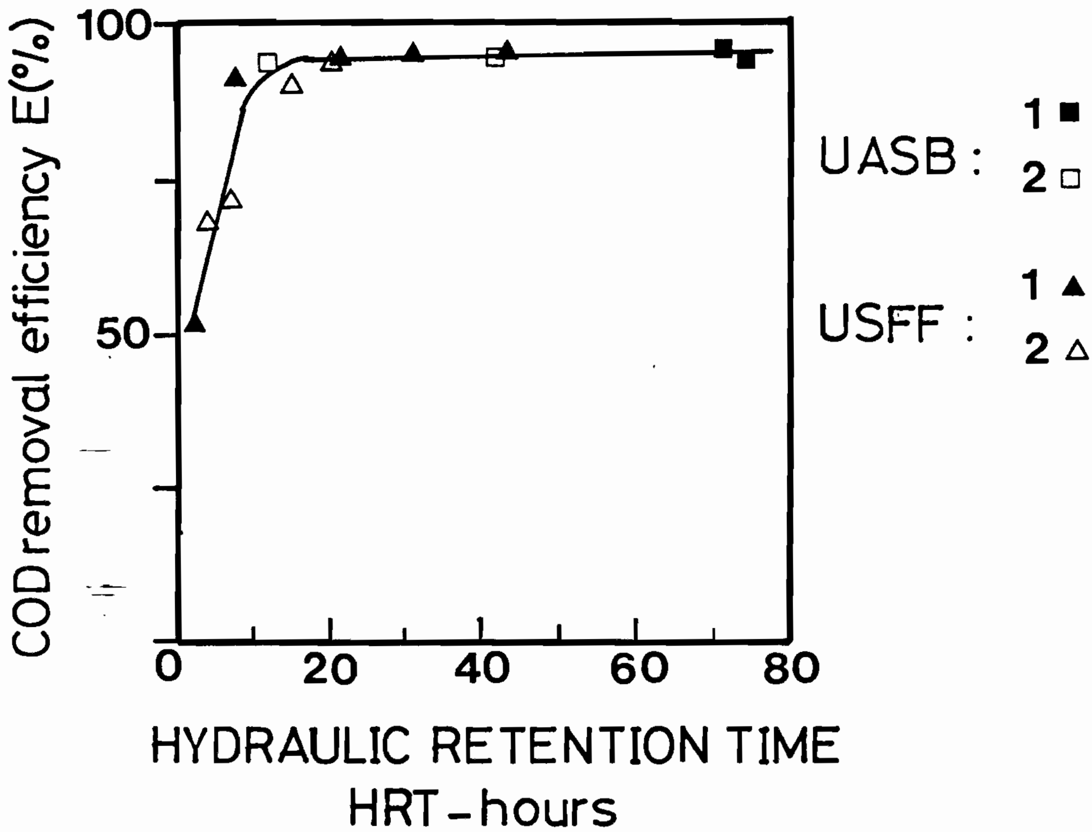

Fig. 3. Effect of the variation of the HRT on the efficiency of COD removal.

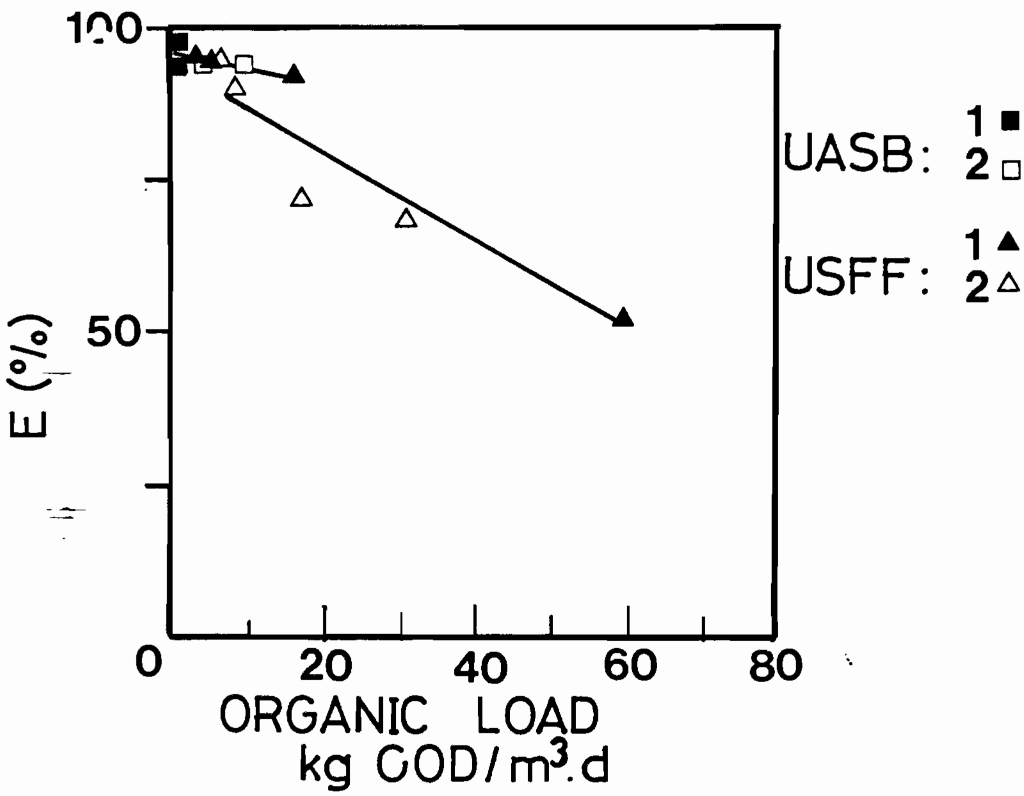

Fig. 4. Effect of the variacion of the organic load on the efficiency of COD removal.

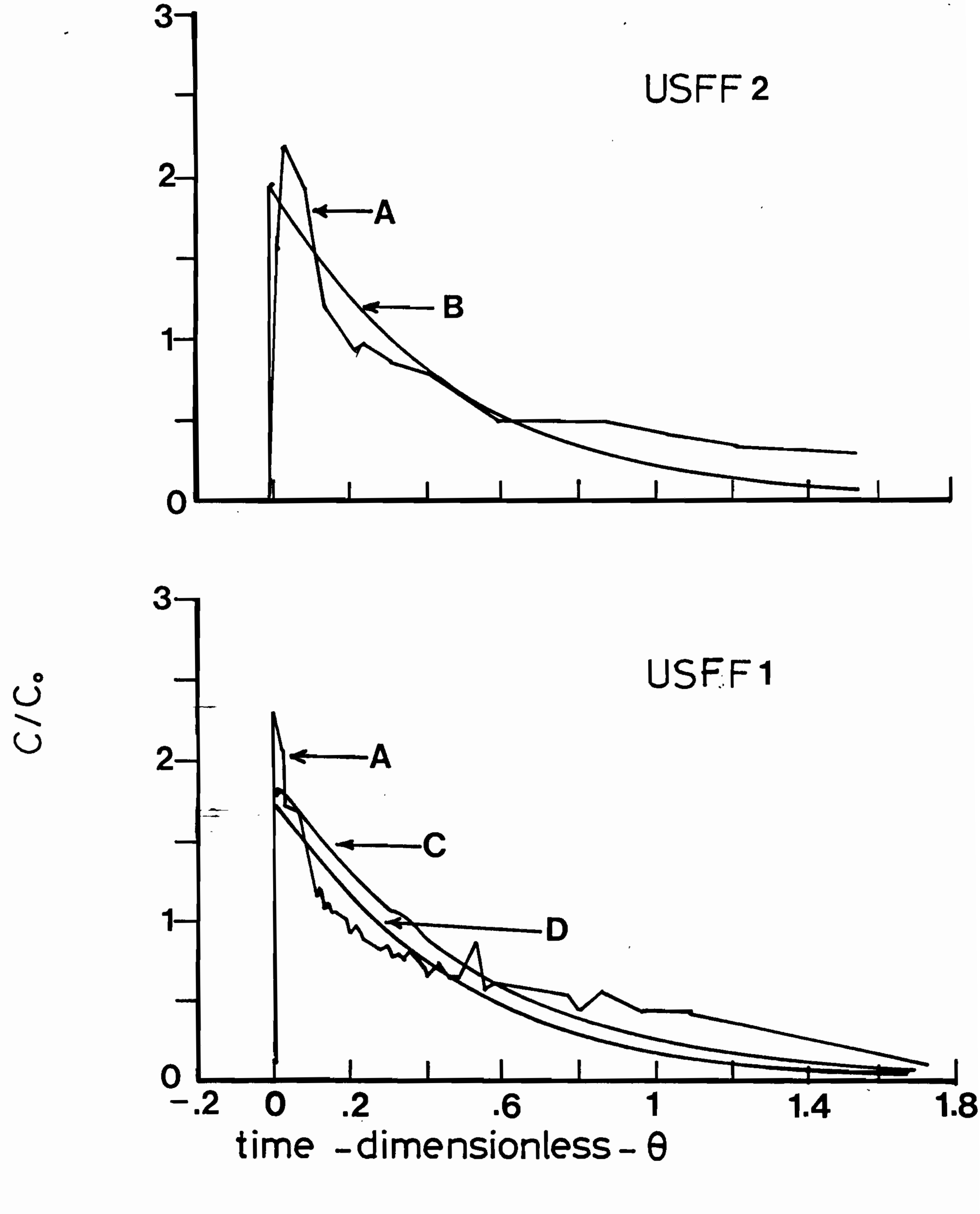

Fig. 5. Residence time distribution evaluation for the FF reactors: experimental and simulated response curves for a pulse tracer input. A: experimental curve from tracing study, B: adjusted curve (a completely mixed reactor with 10 % dead zone and 60 % short circuit), C: adjusted curve (a completely mixed reactor with 47 % dead zone), D: adjusted curve (a completely mixed reactor with 20 % dead zone and 65 % short circuit).

sucrose allows facultative anaerobes to use the dissolved oxygen. Since some sucrose was added from the beginning to the reactors inoculated with adapted activated sludge (UASB and F.F. 2), it is not possible to state which inoculum is better to start-up the reactors. Nevertheless, Weimin et al. (1987) found that the activated sludge contained a great number of methanogenic bacteria (10 /g SS); furthermore, it is known that methane production by the rumen is not based on the acetoclastic reaction, contrarily to industrial anaerobic digestor (Hobson,1982), and that rumen bacteria have very specific nutritional requirements, which makes difficult their cultivation without growth factors. In another hand, the texture of both inocula was different . The fresh cow manure (ochre color), contained a great amount of small fibers of very low density which were not retained by the 0.96 mm mesh and which flow out of the reactor during the start-up period, increasing the amount of VSS and the COD in the effluent; in return, the activated sludge from the secondary settler (black color) already presented evidences of small granules (0.5 mm of diameter). The particulate structure of this sludge might provide good resistance to environmental changes, such as oxigen concentration and redox potential. Upon these considerations, it might appear more advisable to use activated sludge as an inoculum for anaerobic reactors.

OPERATION AND EFFICIENCY.

Both types of reactors present similar efficiency, then economic considerations will make the difference in treating concentrated waste waters. As a matter of fact, the UASB reactor would be more economic, since it does not require any packing. This will not be valid to treat diluted waste waters, such as municipal waste waters, at temperatures below 20° C, in this case differences migth appear between the two processes (Noyola et al, 1988). However, it must be noted that others selection criterions should be taken into account, such as special characteristics of the effluent to be treated. In this respect, Parkin and Speece (1983) reported a greater resistance to toxic compounds for anaerobic filter than for stirred anaerobic reactors.

BIOMASS CONTENT.

Sludge content in the UASB 2 was determined when it was operated at a organic load of 9.9 Kg COD/m^3.d with an efficiency of 94%. The rate of COD removal per kg VSS.d (rx) was calculated: rx= 9.3 Kg COD/Kg VSS.d. Which is closed to the maximum rate reported by Henze and Harremoes (1983) (13 Kg COD/Kg VSS.d). This rate is valid if only the totality of the VSS fraction is composed of 100% active methanogenic bacteria. If there are others groups of bacteria, like it occurs when the feed and inoculum are complex, the VSS will include all the different types of bacteria, this will reduce the value of rx max to approximately 1 Kg COD/Kg VSS.d, this value is often reported in the literature (Lettinga et al., 1980; Henze and Harremoes, 1983; Kennedy and Droste, 1986; Wu et al., 1987). Furthermore, Lin et al. (1986), reported a rx max of 17,6 Kg COD/Kg VSS.d with a stirred anaerobic reactor feeded with a mixture of acetate, propionate, butyrate (2:1:1). These authors concluded that the metanogenic consortium had a rx max higher, when it is fed with a mixture of volatile fatty acids instead of the individual components of the mixture. In our work, the carbon source of the feed allowed the acetogenic microflora (with propionate) and methanogenic microflora (with acetate and hydrogen) to grow. The close syntrophic relationship between these 2 groups of bacteria makes the acetogenic microflora unable to grow without the hydrogenophilic methanogens (McInerney and Bryant, 1981). Then, this strict interdependency of the microbial groups of the sludge reactor, makes possible to admit that both groups of microorganisms behave as a methanogenic whole. The rate of substrate consumption found, allows us to think that the VSS content was nearly saturated. The specific rate of methane production was 3.46 l/g VSS.d (standard conditions), which permits to calculate a value of 0.37 l CH_4/g COD removed. This is similar to the one proposed by McCarty (1964) (0.35 l/g COD). This specific rate is higher than those proposed in the literature for the acetoclastic methanogenic bacteria: 1 l CH_4/g VSS.d (Valcke and Verstraete, 1983), 3.02 l CH_4 / g VSS.d (Lawrence and McCarty, 1969). But in our study, we must consider that methane was produced from both acetate and propionate (through acetate and hydrogen). A stoechiometric calculation based on UASB 2, give the contribution of each substrate to the methane production: 71% from the added acetate, 17% from the acetate produced from propionate and 12% from the hydrogen, (then 29% from the propionate). From what it can be calculated that the acetoclastic methanogenic bacteria account for 3.04 l of CH_4 of the total specific rate of methane production, this value is similar to that reported by Lawrence and McCarty (1969).

From the previous considerations, it can be stated that the biomass of UASB 2 presented a high methanogenic activity, and that nearly 100% of the VSS was an active methanogenic biomass. This is in agreement with one of the characteristics of the UASB reactor, which is the selection of a highly active granular biomass (Lettinga et al, 1980).

With respect to the fixed film reactors, the immobilized biomass can be estimated indirectly by determining the liquid volume in the reactors before the inoculation and at the end of the experiment. The calculated biofilm thickness for FF1 and FF2 were 1.33 mm and 2.14 mm respectively. If we used the superficial density given by Kennedy and Droste (1986) (0.116 kg VSS/m^3) for a biofilm thickness of 2.6 mm, applying a correction factor which considers the thickness as directly proportional to the density, it is found a total content of VSS of 62,3 g for FF1 and 100.3 g for FF2. The speculative character of this kind of calculations prevents to make definitive conclusions, but can be used as a base for comparisons with the UASB reactors.

Using the last set of data of operation for each fixed film reactor (fig. 3 and 4):(i) FF1: 60 kg COD/m^3.d, HRT: 2 h, efficiency: 52.5% ; (ii) FF2: 31.52 kg COD/m^3.d, HRT: 4 h, efficiency:68.5% , it was possible to calculate the following rx (Kg COD/g VSS.d): 2.37 (FF1), 1.02 (FF2) and the rates of methane production (l CH /g VSS.d): 0.73 (FF1), 0.27 (FF2). According to these values, the fixed film reactors had accumulated a biomass of low activity. However, tracers experiments (Fig. 5) shown the existence of numerous dead-spaces and short-circuits in these reactors. As a consequence, the real HRTs and amount of irrigated biomass must be inferior to the values previously calculated. On this basis, the specific rates of COD consumption and methane production might be greater, taking into account only the VSS fraction of the active part of the fixed film reactors.

Therefore, not only the effluent distribution must be made properly at the bottom of the UASB reactor (Lettinga et al, 1980, 1982), but the same care must be taken for the upflow fixed film reactors: the canals which are formed in the packing material generate dead-spaces and short-circuits, furthermore the gas bubbles produced an effect of upward pumping, which increases the possibilities of short-circuit.

CONCLUSION.

Both type of reactors present similar and satisfactory efficiencies with respect to COD consumption at organic loads up to 15 kg DCO/m^3.d.

An highly active biomass was obtained with the UASB reactor. However, efficiencies of the fixed film reactors should be increased if a good process design is used, such as an efficient liquid distribution at the reactor bottom. The reactor packing favours the formation of dead-spaces and short-circuits. Economical calculations and substrate specificity (e.g. toxicity) will command the choise of the process which will be used for a determined application.

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