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FACTORS INFLUENCING FORMATION AND MAINTENANCE OF GRANULES IN ANAEROBIC SLUDGE BLANKET REACTORS (UASBR)

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SUMMARY

Four, 20 L UASB reactors were operated under different hydrodynamic regimes continuously for more than 150 days. The influence of superficial liquid upflow velocities over the range 0.25 to 1.5 m h^{-1}, on granule activity and characteristics was investigated, maintaining constant temperature (35°C), and volumetric loading rate (6.2 g COD L^{-1} day^{-1}). Reactor pH, COD removal, VFA concentration, bed height and gas production were continuously monitored and evaluated. It was found that hydrodynamic conditions can influence the size of granules, and their settling characteristics. Low upflow velocities (0.25 and 0.5 m h^{-1}), are favourable for granule growth and accumulation. At high upflow velocities (1.0 and 1.5 m h^{-1}), no sludge accumulation and disintegration of larger granules were observed.

INTRODUCTION

The formation of granules from anaerobic sludge and their maintenance are influenced by a number of parameters. The composition and temperature of the wastewater, reactor configuration, loading rate, and hydrodynamic conditions seem to be the most important parameters.

One problem industrial UASB reactors may have is the occasional loss of granulation and subsequent washout of granules from the system. This may be attributed to hydraulic stresses on granules.

In UASB reactors hydraulic stresses are produced by influent liquid streams, from feed and recycle lines. Hydraulic conditions in UASB reactors are generally characterized by the superficial liquid upflow velocity in the reactor, often simply referred to as the upflow velocity. The upflow velocity employed in most of the laboratory and industrial UASB reactors is about 1 m h^{-1} (Hulshoff Pol et al., 1987), although values up to 6 m h^{-1} in laboratory-scale reactors have been also reported (Guiot et al., 1988). At high upflow velocities granules may be disintegrated, and the resulting fragments washed out of the reactor. At small upflow velocities, a hollow core may appear within the granules; that, if filled with biogas, can float the granules out of the reactor (Kosaric et al., 1989).

In this work, the influence of upflow velocity on the activity and characteristics of granular sludge, at constant temperature, medium composition, and volumetric loading rate was investigated.

MATERIALS AND METHODS

Reactor Operation

- Four 20 L reactors (R1, R2, R3 & R4) were used with continuous flow operation, see Figure 1. The feed (Table 1) was prepared daily.
- The reactors were operated at a constant temperature of 35°C.
- The volumetric loading rate was constant at 6.2 g COD L^{-1} day^{-1}.
- The initial upflow velocity was 0.5 m h^{-1} in all reactors. On day 49, step changes in upflow velocities were performed as shown by Table 2.
- The anaerobic granules were provided by Paques-Lavalin Inc., Montreal, and had previously been used in a pilot-plant reactor treating pulp mill wastes at Domtar Inc. in Canada.

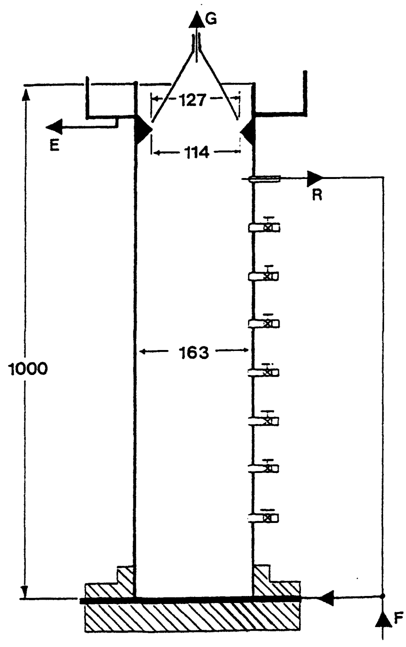

Fig. 1. Schematic of the UASBR. (dimensions in mm)

Table 1 Composition of Synthetic Feed

COMPONENT	CONCENTRATION (mg/l)
Acetic Acid	2 000
Propionic Acid	500
Butyric Acid	500
NaOH	pH adjustment
K_2HPO_4	200
$(NH_4)_2SO_4$	20
NH_4HCO_3	650
$NaHCO_3$	2 250
Yeast Extract	100
$CaCl_2 \cdot 2H_2O$	367.5
* TMS (Trace Metal Solution)	2 mL/L
* TMS	
$FeCl_2 \cdot 4H_2O$	2 000
H_3BO_3	50
$ZnCl_2$	50
$CuCl_2 \cdot 2H_2O$	40
$MnCl_2 \cdot 4H_2O$	500
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	50
$AlCl_3$	30
$CoCl_2 \cdot 6H_2O$	150
$NiCl_2 \cdot 6H_2O$	500
Concentrated HCl	1 mL
Distilled Water	to make 1 litre

Table 2 Reactor Operation after Step Change in Upflow Velocity

Reactor	Feed Flow Rate mL min^{-1}	Feed Retention Time h	Recycle Flow Rate mL min^{-1}	Upflow Velocity m h^{-1}	Superficial Inlet Velocity m s^{-1}
R1	22.5	14.8	65	0.25	0.04
R2	22.5	14.8	152	0.50	0.08
R3	22.5	14.8	326	1.00	0.16
R4	22.5	14.8	500	1.50	0.24

Analysis

- Chemical Oxygen Demand (COD), by the method of Knetchel (1977).
- Volatile Fatty acids (VFA), by gas chromatography (Varian model 3400 gas chromatograph; using a 4 mm x 36" glass column, packed with 60/80 Carbopack C/0.3% Carbowax 20M/0.1% H_3PO_4; using a Varian model 4270 integrator).
- Total Suspended Solids (TSS) and Volatile Suspended Solids (VSS), according to Standard Methods (1980).
- Gas Production, with a dry gas meter (Canadian Meter Company Ltd.)
- pH, with a Fisher Accumet pH meter (model 600) equipped with a glass standard electrode.
- Granule Settling Rate, was measured according to the method described by Andras et al. (1988). The granules were distributed in a vertical tube (Figure 2), by water pumped through at different velocities. Granules washed out at each velocity were collected on filter papers, then dried overnight at 104°C. The fractional percentage of TSS collected by each filter paper was determined.

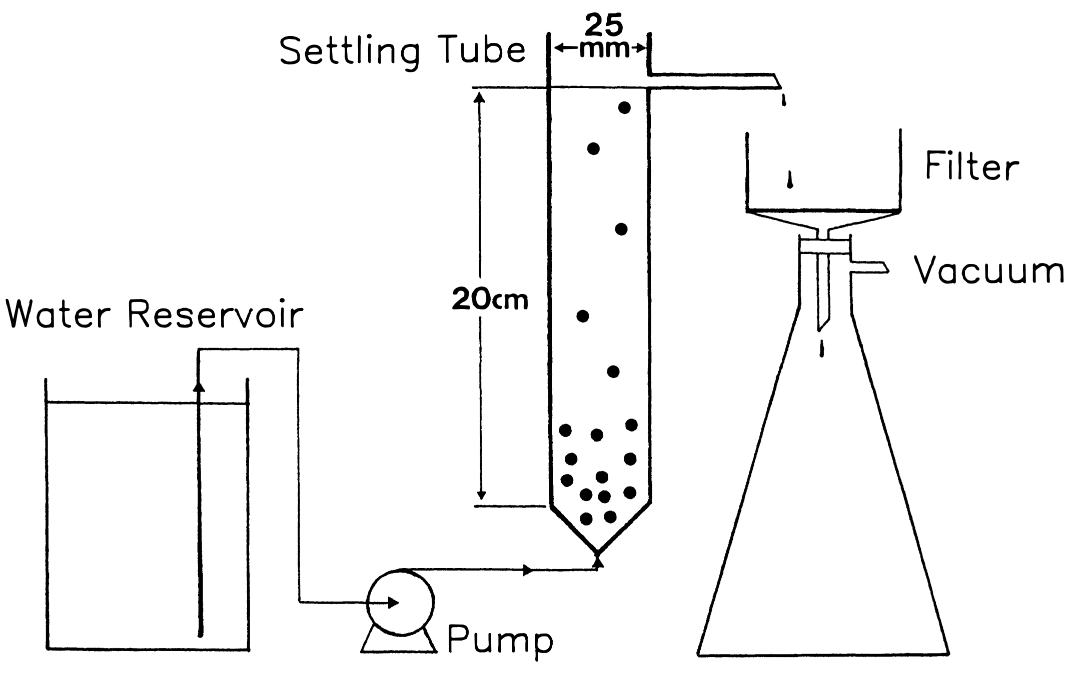

Fig. 2. Schematic of the granule settling rate apparatus.

RESULTS

The process parameters were monitored chronologically for each reactor. The initial amount of granules in the reactors was about 180 g VSS. The data showed very high COD and VFA conversion even though portions of the granular beds were removed on several occasions (on day 49 - 15 g VSS, on day 77 - 15 g VSS, on day 82-15 g VSS, on day 116 - 25 g VSS, on day 127 - 10 g VSS, and on day 131 - 10 g VSS. The COD conversion dropped after each removal but within a few days returned to about 100%.

It was observed that reactors with high upflow velocities returned faster to 100% COD conversion.

On day 134, when the next 40 g VSS were removed, the reactors did not return to 100% COD conversion. On this day the amount of granular sludge in the reactors was about 82 g VSS.

In the next part of experiment, after day 134, the strong influence of upflow velocity on granule characteristics was evidenced. Granules accumulated in reactors with low upflow velocities (0.25 and 0.5 m h^{-1}), while, in reactors with high upflow velocities (1.0 and 1.5 m h^{-1}), there was a net loss of granules. The variation of granule accumulation between reactors, after about two months of reactor operation, is presented by Table 3. High COD conversion in all reactors, may suggest that additional biomass was also produced in reactors with high upflow velocities; since, biomass yield must be proportional to COD removal. However, these cells were washed out in the effluent. In support of this, higher VSS concentrations were measured in the effluent streams from these reactors.

Table 3 Accumulation of Granules at Different Upflow Velocities in the Reactors

Reactor	R1	R2	R3	R4
Upflow velocity, m h^{-1}	0.25	0.5	1.0	1.5
Period of observation, days	40*	55**	40*	55**
Initial VSS, g VSS	82.5	82.5	82.5	77.0
Final VSS, g VSS	134.8	101.8	80.8	74.3
VSS accumulation, %	+63	+24	-2.1	-3.5
VSS accumulation per day, %	1.6	0.44	-0.05	-0.064

* from day 134 to day 174 ** from day 134 to day 189

The high velocity of the liquid streams from the inlet ports (Table 2), probably disintegrated most of larger granules within the reactor bed; while the high upflow velocity promoted washout of smaller particles out of the reactors. This assertion is confirmed by comparing the settling rates of granules from all reactors, as described in the materials and methods section. The following four classifications of settling rate were set: slow (0 - 30 m h^{-1}), medium (30 - 60 m h^{-1}), fast (60 - 90 m h^{-1}), and very fast (> 90 m h^{-1}).

For the first phase of the experiment, an upflow velocity of 0.5 m h^{-1} was maintained in all reactors. During this period, the fractions of slow, medium, fast, and very fast settling granules were approximately the same in all reactors (Figure 7a). The step change in upflow velocity was performed on day 49; about 120 days after this, differences between granules in the reactors operating at small upflow velocities (0.25 and 0.5 m h^{-1}), and high upflow velocities (1.0 and 1.5 m h^{-1}) as depicted by Figure 7b, were observed. In the reactors operated with lower upflow velocities, the fraction of granules falling in the slow settling rate category decreased, and the fraction of fast settling granules increased. Conversely, in reactors with higher upflow velocities, the fraction of granules with slow settling rates increased; while, the fraction with fast settling rates decreased.

These results show that granules enlarge at lower upflow velocities, and, at high upflow velocities, diminish due to shearing. It cannot be explained why the fraction of granules with very fast settling rates increased at both low and high upflow velocities.

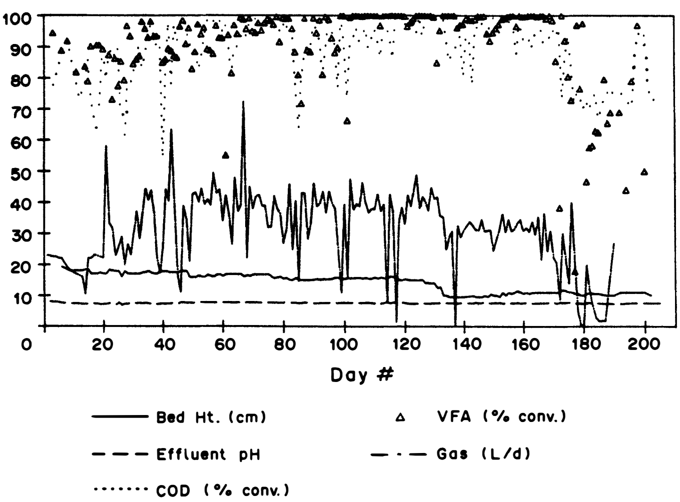

Fig. 3. Performance of reactor R1.

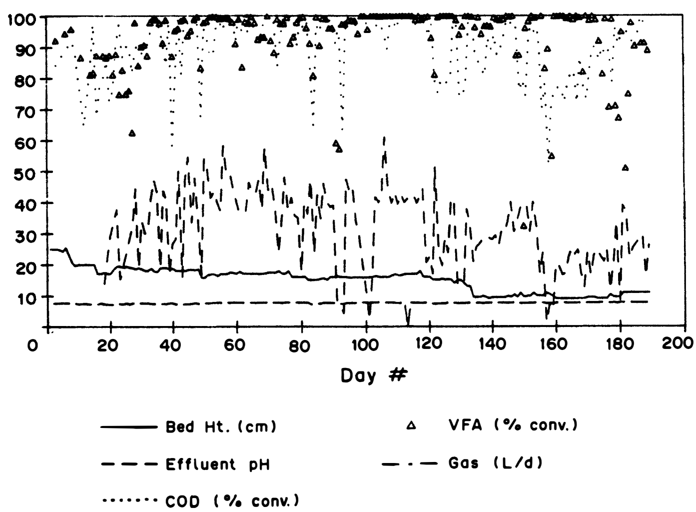

Fig. 4. Performance of reactor R2.

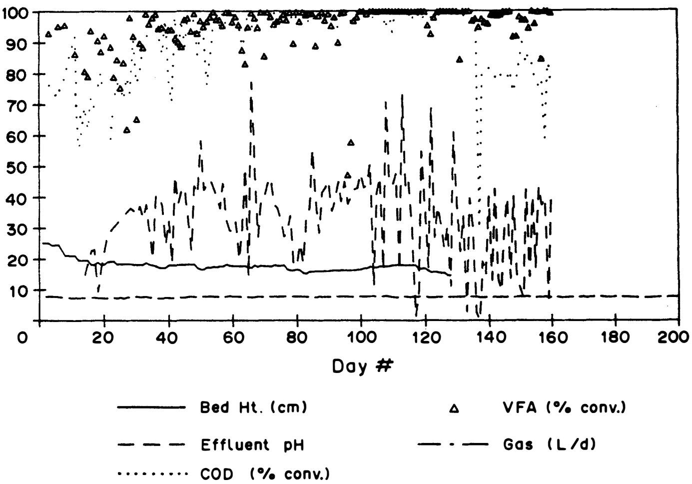

Fig. 5. Performance of reactor R3.

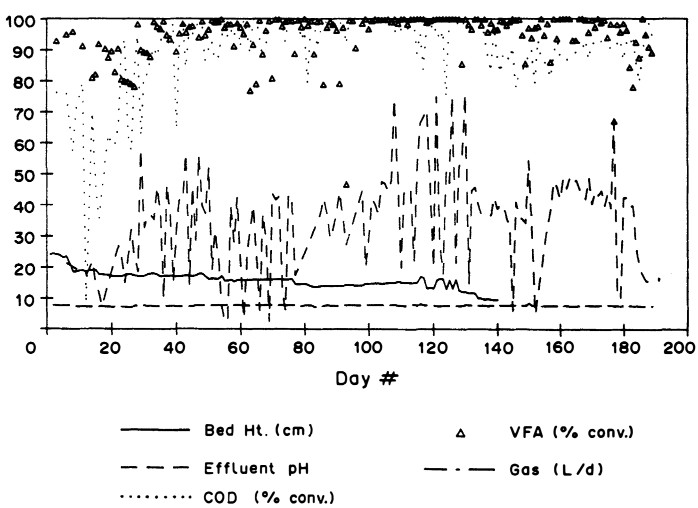

Fig. 6. Performance of reactor R4.

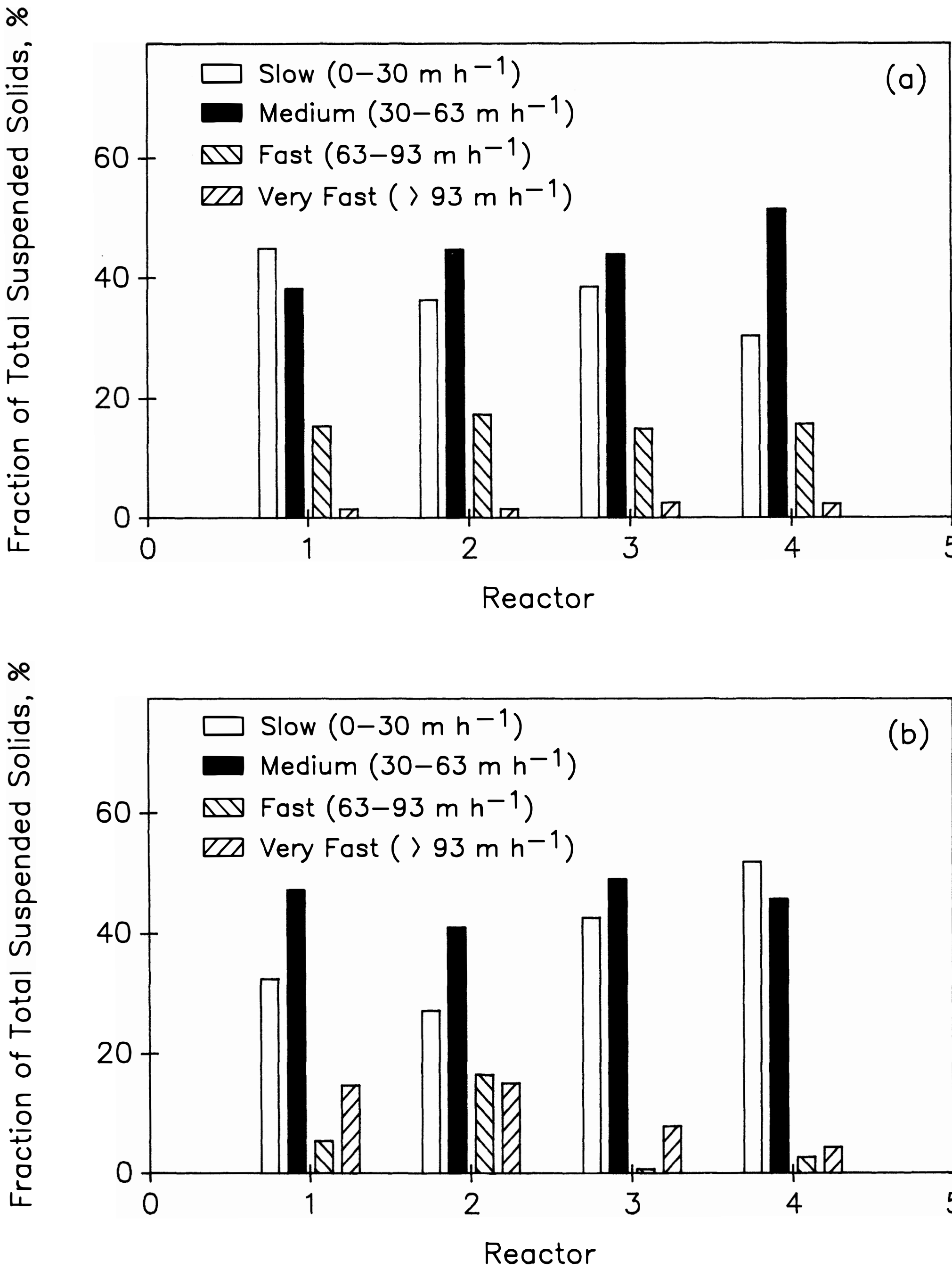

Fig. 7. Profiles of granule settling rates for each reactor.
(a) - Before the step change in upflow velocity.
(b) - 120 days after the step change in upflow velocity.

CONCLUSIONS

The hydrodynamic conditions in a UASB reactor influence granule activity and characteristics. At low upflow velocities (0.25 and 0.5 m h^{-1}), granules accumulate in the bed, they enlarge, and the fraction of granules with high settling rate increases.

At higher upflow velocities (1.0 and 1.5 m h^{-1}), granules are partly disintegrated and washed out of the bed. The total mass of volatile suspended solids as granules in the reactor bed, reduces at a slow rate; also, the fraction of granules with slow settling rates increases, and the granule size distribution becomes more uniform.

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