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BIOENERGY PRODUCTION USING HIGH RATE, LOW F:M ANAEROBIC DIGESTION

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ABSTRACT: Any scheme to create renewable energy from waste streams will undoubtedly utilize some degree of anaerobic conversion of organics to biogas (a mixture of methane and carbon dioxide). Traditionally, anaerobic treatment has been utilized as a pretreatment step (e.g., anaerobic lagoon) or as a sludge stabilization step at the tail end of a treatment scheme. The difficulty in using anaerobic digestion as the main treatment step is threefold: anaerobic bacteria are slow growers, anaerobic bacteria are difficult to separate from the non-productive solids, and toxic and/or inhibitory conditions can cause the digestion process to deteriorate to the point of process failure. The research presented here takes a fresh look at anaerobic digestion and provides an alternate strategy that reduces the required detention time and eliminates the necessity of operating at mesophilic or thermophilic temperatures. The anaerobic treatment of municipal wastewater was successfully performed with the Static Granular Bed Reactor (SGBR). Five-day, carbonaceous biochemical oxygen demand ($CBOD_5$) and total suspended solids were reduced to less than 30 mg/L in the effluent at HRTs of 24 hours and above and at an HRT of eight hours. Suspended solids accumulated within the reactor on top of the granule bed, and were easily wasted from a valved port. Due to the limiting rate of hydrolysis, biodegradable suspended solids were not fully metabolized, and methane recovery of chemical oxygen demand (COD) removed by the reactor was incomplete.

Keywords: Anaerobic, municipal, granule, Static Granular Bed Reactor, hydrolysis, substrate affinity

1 INTRODUCTION

Secondary municipal wastewater treatment is almost exclusively accomplished via aerobic biological processes, which have the drawbacks of high energy expenses associated with aerating the system and high sludge production due to a yield of roughly 0.5mgVSS/mgCOD. Anaerobic treatment, on the other hand, requires no aeration, produces high energy methane gas, and generates much lower yields of sludge between 0.1 to 0.2mgVSS/mgCOD. Lettinga *et. al.* [1] was able to effectively treat municipal wastewater at temperatures of 20ºC or higher in an upflow anaerobic sludge blanket (UASB) reactor. Kato *et. al.* [2] showed theoretically that a UASB could treat wastewaters with a strength as low as 187 mgCOD/L at an organic loading rate (OLR) as high as 5 gCOD/(L·d). A problem with treating municipal wastewater with anaerobic systems is the low substrate affinity of methanogens [3]. Another study was conducted that suggested the key to municipal wastewater treatment with anaerobic technology was suspended and colloidal solids removal [4]. Elmitwalli *et. al.* [4] indicated that the low rate of hydrolysis was problematic, but could be accomplished with a two-step, anaerobic filter (AF) + anaerobic hybrid (AH) reactor, system.

A study was developed to examine treatment of municipal wastewater with a unique anaerobic reactor technology, the SGBR. The SGBR is a simple, downflow anaerobic reactor [5] previously demonstrated to be effective at treating synthetic wastewater composed of 1gCOD/L non-fat dry milk, a pork-slaughterhouse wastewater and a synthetic industrial wastewater high in sulfates [6]. The SGBR was shown to have long solids retention times (SRTs), in excess of 300 days [6], as a result of excellent solids separation, which contributed to its efficient treatment. Laboratory and pilot-scale SGBR studies have demonstrated the ability of the system to treat a wide variety of waste streams including pulp and paper wastewater [7], industrial wastewater from dairy processing [8], swine manure [9-10], pork slaughterhouse wastewater [11], and synthetic wastewater [12].

The goal of this study was to establish if the SGBR would adequately remove $CBOD_5$ and TSS to meet surface discharge standards, and to determine the effect of hydraulic retention time (HRT) on effluent concentrations.

2 METHODOLOGY

A lab scale SGBR (Figure 1) was used to treat municipal wastewater at 25ºC with HRTs of 48, 36, 24, 18, 12, and 8 hours. Wastewater that had undergone preliminary treatment, screening and grit removal, from the Ames Water Pollution Control Facility (AWPCF) in Ames, Iowa was treated by an 11.8 Liter SGBR. The wastewater was preserved in a refrigerator and received no further treatment prior to being fed into the SGBR. Chemical oxygen demand (COD), $CBOD_5$, TSS, gas composition, alkalinity, and volatile fatty acids (VFAs) were routinely measured using standard methods [13] to indicate the reactor's performance effectiveness and to gauge its health. Wastewater strength varied (Table 1), but overall average values for COD, $CBOD_5$, and TSS were 388mg/L, 123mg/L, and 220mg/L, respectively. Initially, a low $CBOD_5$ was encountered due to problems with preservation. Headloss increased in the reactor as a result of gas entrapment and TSS accumulation on top of the granule bed. Routine backwashes were used to eliminate excess headloss as previously encountered [14].

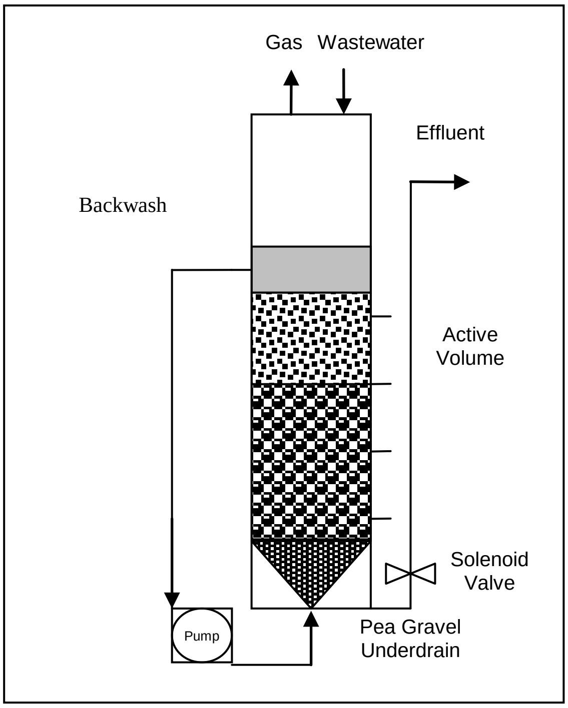

Figure 1. Laboratory-scale SGBR reactor.

Chemical oxygen demand was measured using the closed reflux, titrimetric method with 20 x 150 mm culture tubes. Whatman GF/C glass microfibre filters were used for suspended solids testing. Volatile fatty acids were measured using the distillation method [13]. Methane concentrations were measured with gas chromatography using Gow Mac Instrument Company Series 350 thermal conductivity detector with Hayesep column C3111220002. Gas production was measured using the Cole Parmer loop-powered gas transmitter and monitor/totalizer (model), which meters gas based on differential pressure sensing plates.

3 RESULTS

The study showed that the SGBR removed $CBOD_5$ and TSS to meet the typical surface water discharge standard of 30 mg/L TSS and 30 mg/L $CBOD_5$ at HRTs of 24 hours or higher and eight hours (Table 1). At HRTs less than 24 hours, $CBOD_5$ was reduced to 57 mg/L or less. It was discovered that dissolved organic gases contributed to $CBOD_5$ in the effluent during operation at the 18 and 12 hour HRT periods based on comparison of $CBOD_5$ concentrations for samples that were and were not air sparged. Consequently, effluent samples were air sparged for five minutes prior to testing for $CBOD_5$ during operations throughout the eight hour HRT period. The TSS concentrations in the effluent were highest during startup, averaging 29 mg/L, but dropped thereafter and averaged 6mg/L at an eight hour HRT. Effluent COD was reduced to between 57mg/L and 77mg/L for all HRTs. Removal efficiency for COD was optimal at a HRT of 18 hours for the SGBR (Figure 2). Except for startup, COD removal varied little from 74-84%.

Table 1. Influent Wastewater Characteristics

HRT	TSS, mg/L	$CBOD_5$, mg/L
48	106.3 ± 58.4	28.9 ± 6.6
36	273.9 ± 72.2	169.5 ± 96.2
24	301.1 ± 99.1	135.2 ± 68.3
18	163.0 ± 55.6	83.9 ± 40.2
12	236.0 ± 109.2	166.9 ± 105.5
8	187.2 ± 99.7	106.9 ± 38.8

Table 2: SGBR Effluent Characteristics

HRT	TSS, mg/L	$CBOD_5$, mg/L
48	29.1 ± 11.7	17.4 ± 6.5
36	10.6 ± 2.9	23.9 ± 6.4
24	11.7 ± 2.4	25.6 ± 9.0
18	8.2 ± 3.5	31.3 ± 5.8
12	7.8 ± 4.1	56.8 ± 9.4
8	5.6 ± 3.3	29.8 ± 12.0

High SRTs are required in anaerobic reactors to achieve high levels of treatment. For this study, the SRT in the SGBR was estimated (based on reactor volatile solids and effluent volatile suspended solids concentrations) to vary between eight and 20 years depending on the HRT. At higher HRTs, low effluent suspended solids coupled with high flow rates resulted in SRTs greater than ten years. Suspended solids in the wastewater tended to accumulate on top of the granules in the reactor, and required wasting after six months of operation and then again after one year of treatment.

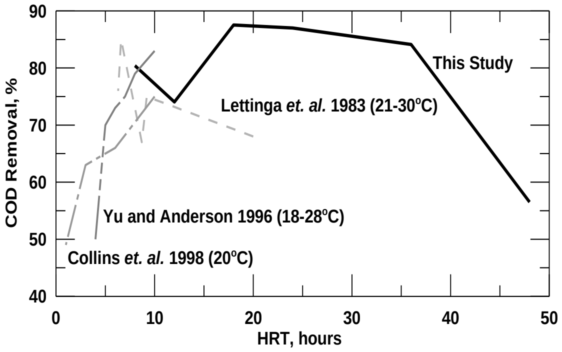

Figure 2. COD Removal as a Function of HRT

Alkalinity and pH were measured for the SGBR (Table 3) to ensure the reactor was operating within an optimal range for methanogens. As observed by the results, pH was reduced slightly from the influent values (influent pH ranged from 7.1 to 7.7), but likely was not responsible for methanogen inhibition. Volatile fatty acids in the effluent were measured between 9 and 30 mgHAc/L. Generation of VFAs was primarily responsible for the slight decline in pH. Carbon dioxide gas concentrations were low ranging from zero to three percent of the total gas composition, but may also have contributed. Alkalinity in Ames wastewater helped to buffer the effects of acidity generated during anaerobic metabolisms.

Table 3. Effluent Characteristics

HRT	Effluent pH	Eff. Alk.	% CH_4
48	7.08 ± 0.23	287.5 ± 17.7	63.7 ± 10.9
36	6.75 ± 0.24	465.0 ± 77.0	60.7 ± 23.9
24	6.80 ± 0.19	337.5 ± 74.3	64.3 ± 5.1
18	6.91 ± 0.20	no data	76.1 ± 7.6
12	7.07 ± 0.33	352.5 ± 31.8	39.1 ± 9.8
8	7.23 ± 0.17	322.5 ± 74.3	22.8 ± 2.0

The methane percent concentration that was generated by the SGBR treating municipal wastewater is shown in Table 3. For HRTs from 18 to 48 hours, methane concentrations were consistently above 60%. However, at HRTs of 12 and eight hours, methane gas concentrations dropped precipitously. Lettinga [1] experienced low methane concentrations when treating municipal wastewater with the UASB reactor and attributed the low concentrations to dilution by nitrogen gas being stripped from the wastewater into the gas. In addition, the dissolved methane in the effluent tends to lower the gas concentration.

Cumulative methane generated by the SGBR was measured throughout the study. The actual cumulative methane curve was compared to the theoretical cumulative methane curve (Figure 3). Actual methane production includes methane gas collected and measured by the gas meter, and dissolved methane calculated to be in the effluent based on Henry's law. Theoretical methane generation was based on an assumed complete conversion of COD removed from the wastewater by the SGBR. Actual and theoretical cumulative methane generated were close while the reactor operated at an HRT of 48 hours. At HRTs lower than 48 hours, the theoretical cumulative methane increased to twice the actual cumulative methane. The disparity likely was caused by solids accumulation within the reactor and COD loss due to sulfate reducing bacteria.

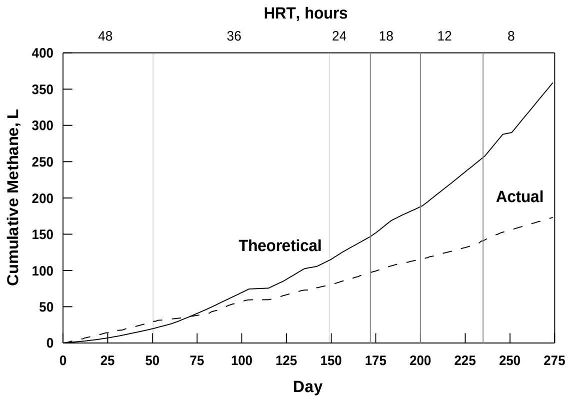

Figure 3. Cumulative methane production

Hydrolysis of solids was apparently the rate limiting step for anaerobic conversion of municipal wastewater. The SGBR was demonstrated to be capable of removing solids from the wastewater. Suspended solids were entrapped within the reactor as indicated by the data. Controlled wastage of solids was the key to treatment of the municipal wastewater with the SGBR. Unfortunately, full energy recovery was not completed due to the low rates of hydrolysis, the dilute nature of the wastewater, and the loss of dissolved methane in the effluent. Static granular bed reactor effluent quality at an HRT of 24 hours was comparable or better than other types of anaerobic treatment reactor types (Table 4).

5 CONCLUSIONS

Anaerobic municipal wastewater treatment offers the advantages of energy efficiency and low sludge production. The low substrate affinity of methanogens and the slow rate of hydrolysis are challenges to making it practical. Treatment of municipal wastewater with the SGBR offers the distinct advantages of long SRTs, and entrapment of suspended solids in the system. Data indicate that the SGBR consistently reduced $CBOD_5$ to less than 30mg/L at HRTs of 24 hours and above. In general, effluent TSS decreased as HRT decreased. Organics removed from the wastewater were converted to methane at an HRT of 48 hours, but accumulated in the system at lower HRTs. Accumulated organics were primarily in the form of suspended solids, which could be wasted from the top of the granule bed.

Table 4. Comparison of anaerobic municipal wastewater treatment studies at mesophilic temperatures.

Reactor[a]	SGBR	ABR	AEBR	UASB	UASB
T, ºC	25	18-28	20	30	16-23
HRT, hr	24	10	10	4	7
COD_{inf}, mg/L	500 ±207	386	196	422 ±68	402
COD_{eff}, mg/L	43±9	64	49	58 ±15	232
BOD_{inf}, mg/L	135 ±17			257 ±26	515
BOD_{eff}, mg/L	26 ±10			36±12	102
TSS_{inf}, mg/L	301 ±49	23[b]	10[c]	246 ±30	379
TSS_{eff}, mg/L	12±3	22	2.4	35±22	50
Refer-ence	This study	[15]	[16]	[17]	[18]

[a]ABR-Modified anaerobic baffled reactor, AEBR-Anaerobic Expanded Bed Reactor
[b] Presettled wastewater
[c] Primary clarifier effluent

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