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Optimizing the Operation of a Two-Phase Anaerobic Digestion System Digesting Grass Silage

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ABSTRACT: This paper examines the optimization of an existing two-phase anaerobic digestion process using grass silage as a feedstock. The system comprises 6 leach beds connected to an upflow anaerobic sludge blanket (UASB). The existing system produced 305 L CH_4 kg^{-1} VS added at an overall retention time of 42 days (6 leach beds emptied and fed sequentially every 7 days in series). The desired improvements were a reduction in retention time with increased methane production. It was noted in the existing system that biogas production and COD levels fell off in the last 2 days of each 7-day cycle. Thus the first change involved reduction in retention time to 30 days (6 leach beds fed sequentially every 5 days in series). This lead to a slight improvement in methane production (310 L CH_4 kg^{-1} VS added). The second change was effected by separation of flows to the first stage (leach beds) and the second stage (UASB) through addition of an extra pump to optimize leaching. This led to an increase in CH_4 production (341 L CH_4 kg^{-1} VS). The overall improvement from the existing system was an increase of 11.8% in methane production and a reduction in size or retention time of 40% (42 days decreased to 30 days retention time).

1. INTRODUCTION

1.1. Anaerobic Reactor Design for High Solid Content Feedstock. Anaerobic digestion (AD) of organic feedstock with less than 12% dry solids is well studied, well published, mature, and implemented successfully at full scale.[1,2] The technology for high solid content substrates (greater than 20% dry solids content) is not as mature or as well published.[3] Dry digestion of high solid content feedstock includes leach bed reactors[4] for the organic fraction of municipal solid waste (OFMSW); plug flow reactors for fruit and vegetable waste;[5] and solid phase reactors with leachate recycling for OFMSW.[6] A good digester should increase solid retention time, minimize hydraulic retention time, decrease reactor size, and reduce process energy input.[7] Good research and development (at laboratory and pilot scale) allowing for reactor optimization is required[8,9] prior to design of a full-scale system.[10]

1.2. Methane Yields from Grass Biomethane Digesters. Considering that the grass silage used in this experiment has an energy value of ca. 18.77 MJ kg^{-1} VS[8] and methane has an energy value of 37.78 MJ m_n^{-3} [8] then the maximum production of methane is of the order of 497 L kg^{-1} VS added. The liquors in silage can increase this number somewhat. Table 1 outlines values encountered in the scientific literature from grass digestion; values range from 165 to 455 L kg^{-1} VS added. A caveat in reading this literature is that the experiments are performed in different countries on different grasses, cut at different times of year. Direct comparison may not be prudent.

Coupling a dry batch digester to an upflow anaerobic sludge blanket (UASB) in theory offers advantages over a simple batch process.[7,16,17] The batch process may be optimized for hydrolysis due to the ability of the batch to process high solid content (up to 50% DS).[8] The UASB may be optimized for methanogenesis due to its ability to accept organic loading rates up to 20 kg of soluble chemical oxygen demand (COD) m^{-3} reactor d^{-1}.[7] Methane production rates of 165 to 390 L kg^{-1} VS added have been observed using such systems.

1.3. Requirement for a Stable UASB System. The successful operation of an UASB is significantly correlated with the development of granules.[20−22] The active biomass concentration of granules together with the influent flow rate and organic loading determines the efficiency of the UASB system. The granulation process is affected by system operating conditions including composition and strength of substrate; system hydrodynamics; presence of trace metals, polymers, and metal ions; and microbial ecology.[23,24] The structure of the granule is affected by the nature of organic compounds in the substrate, the kinetics of substrate degradation, and the concentration of different microbial species.[25,26] The UASB granules are dense with a particle size of 1−4 mm.[27] The stability of the UASB is critical due to its long start-up time and its sensitivity to shock loading.[28−30] Higher COD removal efficiency is achieved when the granules are well developed. Nevertheless, the mechanism involved in the process of granulation is unknown.[21]

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Table 1. Yields of Methane from Grass Silage from Scientific Literature

yield L CH_4 kg $^{-1}$ VS	technology	reference
	batch laboratory processes	
306	dry batch digester at laboratory scale timothy and meadow fescue grasses	Lehtomäki et al. [11]
310−360	batch laboratory scale using different grasses	Mähnert et al. [12]
280−330	batch laboratory	Baserga and Egger [13] and KTBL [14]
350	biomethane potential test	Nizami et al. [7]
361	biomethane potential test	Asam et al. [36]
	two stage (leach beds coupled to high rate reactor)	
305	laboratory scale leach beds connected to UASB at 42-day retention time	Nizami et al. [7]
165−270	laboratory scale leach beds connected to anaerobic filter at 30-day retention time	Yu et al. [18]
		Cirne et al. [19]
390	laboratory scale leach beds connected to high rate digester at 50-day retention time	Lehtomäki andBjörnsson [37]
330	laboratory scale leach beds connected to high rate digester at 30-day retention time	Lehtomäki andBjörnsson [37]
	wet continuous processes	
455	2-stage small demonstration continuously stirred tank reactor with recirculation of leachate at 60-day retention time	Thamsiriroj and Murphy [15]

1.4. Previous Work on Two-Stage Grass Digestion by the Authors. This paper builds on two previous papers by the authors. Nizami et al.[17] undertook experiments in leaching of volatile solids from grass silage and assessed the resultant production of chemical oxygen demand (COD). They found that a flow rate of 100 L d^{-1} sprinkled over a leach bed containing 3.5 kg of baled grass silage (30% dry solids) effected a 70% destruction of volatile solids. Each kg of VS converted to 1.4 kg of COD. In theory each kg of COD can produce 350 L of CH_4. Thus in a theoretical system with a UASB after the leach beds 70% destruction of volatiles should equate to 343 L CH_4 kg^{-1} VS added at 100% UASB efficiency.[17] This is a target of this experimental process

Nizami et al.[7] outlined the commissioning and design of a sequentially fed leach bed reactor complete with an upflow anaerobic sludge blanket (SLBR-UASB). The system consisted of 6 leach beds fed sequentially every 7 days (Figure 1). At a 42-day retention time (6 batches fed every 7 days in series) 68% of volatiles were destroyed and a methane production rate of 305 L CH_4 kg^{-1} VS added was achieved; 86% of methane production occurred in the first 5 days after feeding. Recirculation flow rate over the feedstock was dictated by the upflow velocity of the UASB which cannot exceed 0.1 m hour^{-1}. The maximum flow equated to 100 L day^{-1} which equated to approximately 17 L day^{-1} over each of the six leach beds. Thus the UASB limited the flow, which in turn reduced the potential to leach VS in the grass silage to COD in the liquid stream.

1.5. Focus of Paper. This paper seeks to improve the SLBR-UASB system. Work on leaching[17] showed that there is potential to achieve 70% destruction of volatile solids which in theory should allow a production of 343 L CH_4 kg^{-1} VS added. The commissioned SLBR-UASB system producing 305 L CH_4 kg^{-1} VS added at an overall retention time of 42 days.[7]

The desired improvements are a reduction in retention time with increased methane production.

It was noted in the commissioned system[7] that biogas production and COD levels fell off in the last 2 days of each 7-day cycle. Thus the retention time will be reduced to 6 periods of 5 days (30-day retention time) as opposed to 6 periods of 7 days (42-day retention time). A second pump will be added to the system (Figure 1) allowing differentiation between upflow velocity in the UASB and recirculation rate over the leach beds. Of interest in this paper is the maximum production of methane, the retention time, and the operation of the UASB system including inspection of the granules.

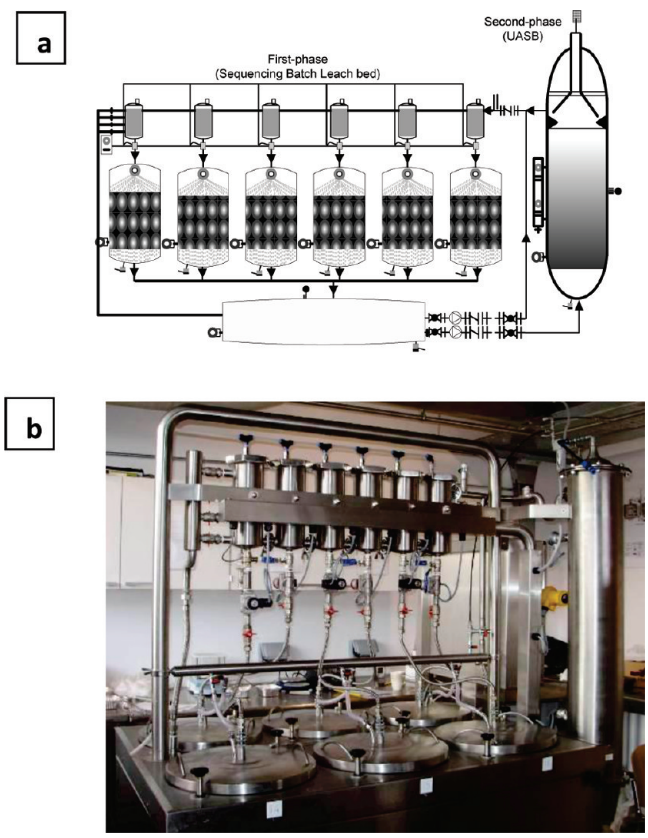

Figure 1. Sequentially fed leach bed reactor complete with an upflow anaerobic sludge blanket (SLBR-UASB): (a) schematic diagram;[7,16] (b) pictorial diagram.

Table 2. Characteristics of Input Grass Silage in the Study Adapted from Ref 17

parameter	measuring unit	value
lactic acid	g kg^{-1} DS	26.95
ethanol	g kg^{-1} DS	11.54
acetic acid	g kg^{-1} DS	3.93
propionic acid	g kg^{-1} DS	0.25
butyric acid	g kg^{-1} DS	1.43
volatile fatty acids (VFA)	g kg^{-1} DS	5.61
ammonia	g kg^{-1} DS	46.18
water-soluble carbohydrates (WSC)	g kg^{-1} DS	49.83
pH		4.3
protein	% DS	9.5
metabolizable energy (ME)	MJ kg^{-1} DS	10
digestibility-value (DMD or D-value)	% DS or D-value	64
silage intake or palatability	g kg^{-1} W0.75	89
potential acid load (PAL)	meq kg^{-1} DS	821
neutral detergent fiber (NDF)	% DS	59
fermentable metabolizable energy (FME)	MJ kg^{-1} DS	8.2
FME/ME ratio		0.81
oil	% DS	3.3
carbon (C)	% DS	43.03
hydrogen (H)	% DS	5.82
nitrogen (N)	% DS	1.61
dry solid (DS)	%	30.66
volatile solid (VS)	%	92.46

Table 3. Relationship between COD, Biogas and Methane Production in the Second Experimental Period

feedstock	
grass silage	21 kg
DS content @ 30%	6.3 kg DS
VS content @92% of DS	5.8 kg VS
VS conversion @ 75%	4.35 kg VS
retention time	30 days
loading rate of 5.8 kg VS/30 days/6 * 17 L leach beds is 1.9 kg VS m^{-3} day^{-1}	
COD production	
COD produced	1.4 kg COD kg^{-1} VS
	4.35 kg VS * 1.4 kg COD kg^{-1} VS
	6.09 kg COD
@ 93% efficiency in UASB	5.68 kg COD/30 days
	0.189 kg COD d^{-1}
loading rate of 6.09 kg COD/30 days/31.4 L UASB is 6.46 kg COD m^{-3} day^{-1}	
methane production	
methane produced @ 93% COD removal efficiency	
	0.35 m^3 CH_4 kg^{-1} COD
	0.35 m^3 CH_4 kg^{-1} COD * 6.09 kg COD * 0.93
	1.98 m^3 CH_4
	0.455 m^3 CH_4 kg^{-1} VS destructed
	0.341 m^3 CH_4 kg^{-1} VS added
biogas and methane production	
methane produced	1.98 m^3 CH_4/30 days
	0.06 m^3 CH_4 d^{-1}
	66 L CH_4 d^{-1}
biogas produced @70.6% methane	2.8 m^3 biogas/30 days
	93.48 L d^{-1}

2. METHODOLOGY

2.1. Characteristics of Grass Silage. The substrate for the digester system was baled grass silage (Table 2) prepared by the Irish Agricultural Institute "Teagasc" at the Grange Research Centre, Ireland. The silage consisted of homogeneous perennial ryegrass. The grass was cut at early mature stage, and was field wilted for 24 h before baling. The bales were wrapped by using polythene stretch-film and stored for 5 weeks. Small square bales of 25 kg were prepared for experimental use. The dry solids content was established as 30%; the volatile solids content was 92% of the dry solids. The silage was macerated to an average particle size of approximately 20 mm. The samples were frozen immediately at −15 °C. The samples were thawed overnight at 6 °C before feeding to the reactor.

2.2. Scheme of SLBR-UASB System. The SLBR-UASB system (Figure 1) combines six leach bed reactors (each with 17-L capacity of feedstock) connected to a high-rate UASB reactor of 31.4 L effective volume. The liquor is sprinkled from six cups (each with 1.5 L capacity) over the feedstock in the six batch leach beds. A leachate high in COD collects in the leachate holding tank and from there may either be pumped into the UASB at a maximum upflow of 0.1 m h^{-1} or recirculated back to the sprinkling cups for discharge over the leach beds. Biogas is produced over the UASB and the liquor is sent back to the sprinkling cups for discharge over the leach beds. Hydrolysis takes place in the leach beds; 1.4 kg of COD is generated per kg of volatile solids (VS) destroyed. Methanogenesis takes place in the UASB; theoretically 350 L of CH_4 is generated per kg of COD destroyed.[17] The leach beds are fed sequentially. For a 30-day retention time bed 1 is fed on day 0, bed 2 on day 5, bed 3 on day 10, bed 4 on day 15, bed 5 on day 20, bed 6 on day 25; bed 1 is emptied and refilled on day 30.

2.3. Experimental Setup. The first 189 days of operation of this SLBR-UASB is described by Nizami et al.[7] This period covered design, commissioning, and system start-up. Commissioning was deemed complete by day 147; design flaws and blockages were solved and a steady biological process was observed between days 148 and 189. In this period methane production was 305 L CH_4 kg^{-1} VS added at a retention time of 42 days effecting a VS reduction of 68%. It was observed that 86% of CH_4 was produced in the first 5 days of the 7-day digester feeding cycle. This paper outlines a reduction of the feeding cycle to 5 days with an overall 30-day hydraulic retention time (HRT). Afterward a second pump is introduced to differentiate recirculation of leachate from the pumped upflow to the UASB. The experimental period is divided in two as follows.

Experimental Scheme 1 (Day 1 to 60). The system is fed with 3.5 kg of grass silage in each leach bed in a 5-day sequential cycle; leading to an overall HRT of 30 days. Initially tap water is used to fill the leachate tank (capacity of 40 L). On the first day of each 5-day cycle (after loading the new batch) the UASB was disconnected and high strength leachate was generated using a

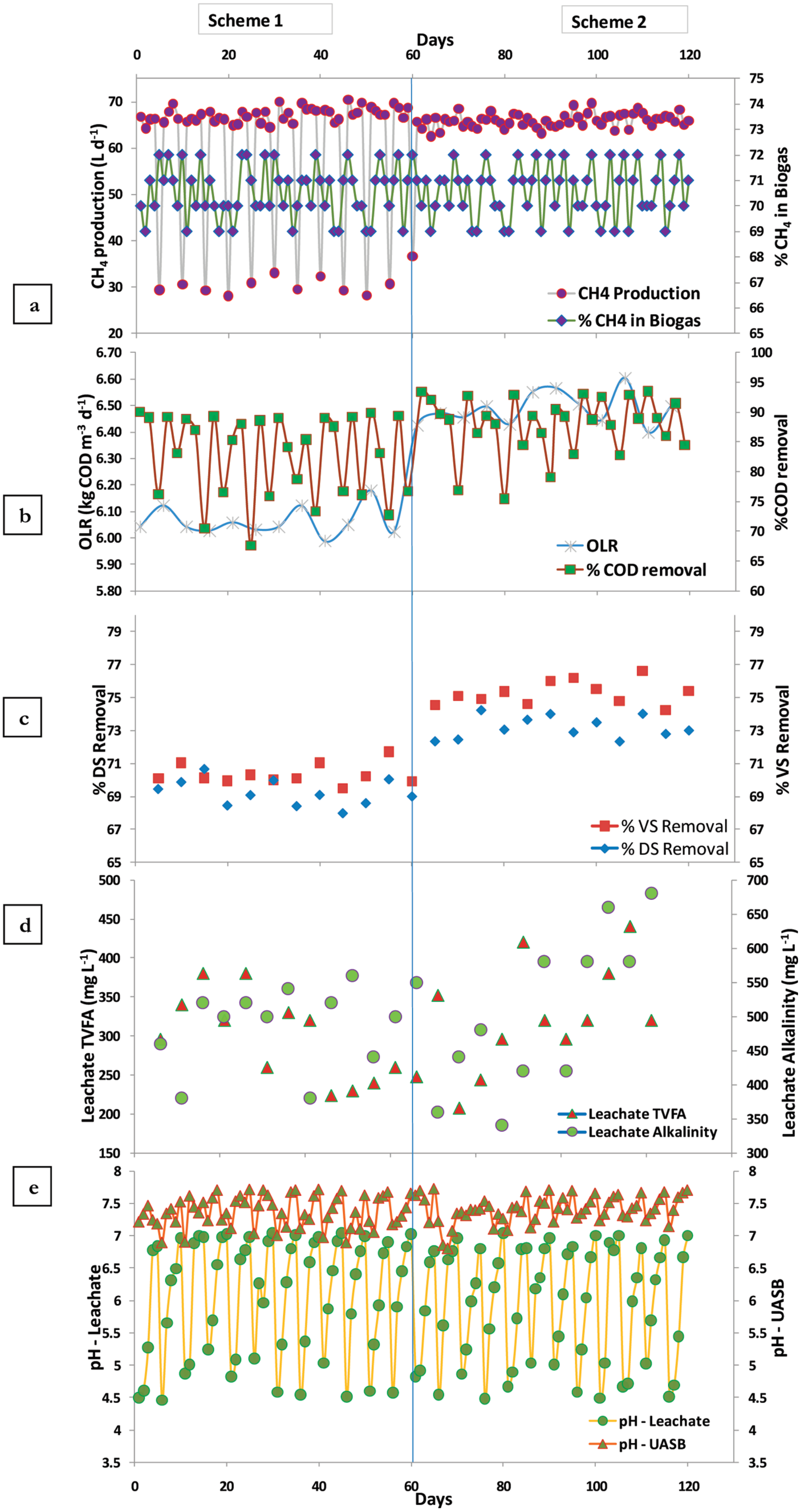

Figure 2. Results of the experimental SLBR-UASB operation.

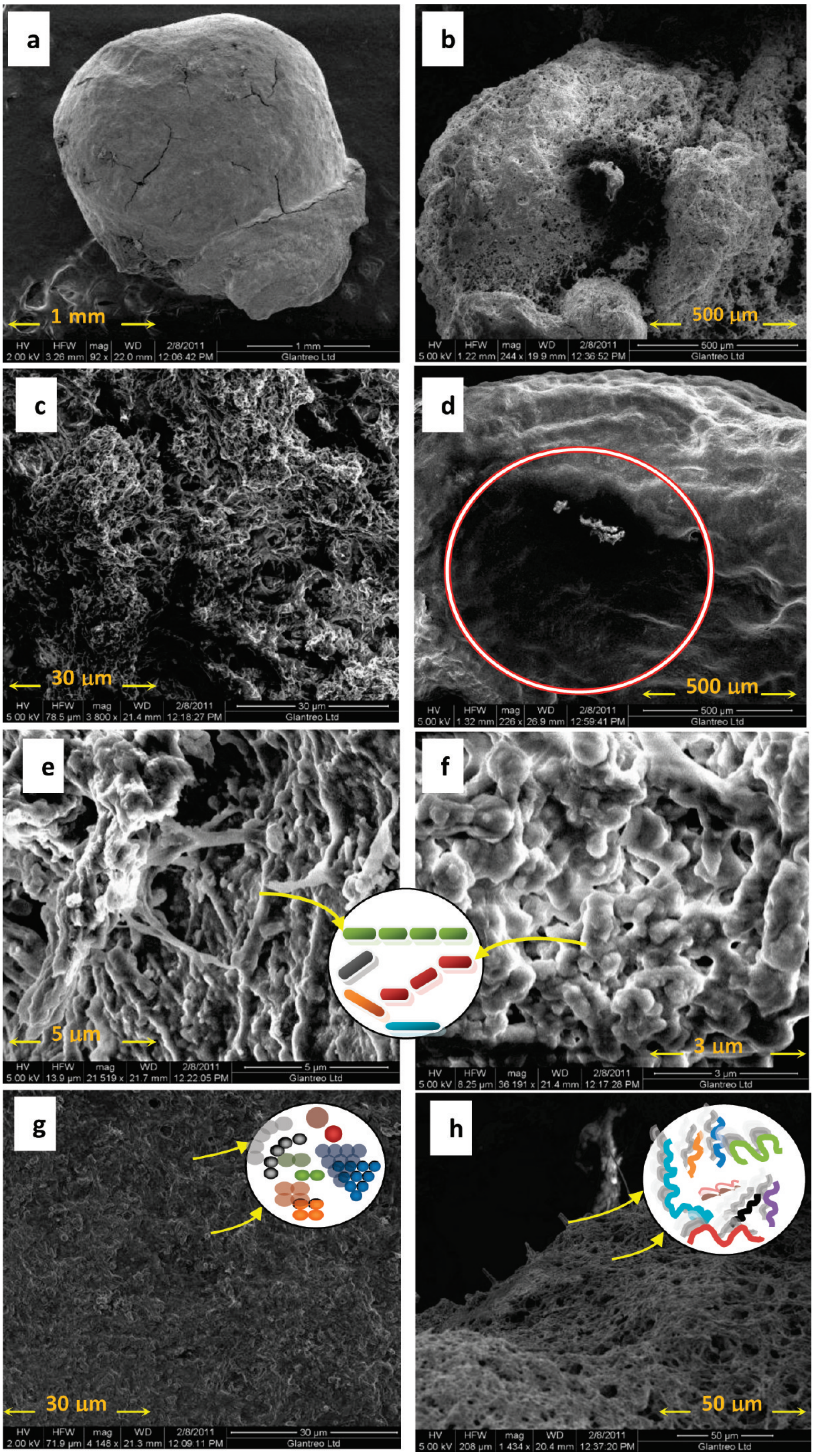

Figure 3. Morphology and structure of granule (see text for details).

high recirculation rate. The pump was set to 1180 L d^{-1} which recirculated the equivalent of 200 L d^{-1} over each leach bed. On day 2 to day 5, the leachate was fed to the UASB at a flow rate of 100 L d^{-1}; generating an upflow velocity of 0.1 m h^{-1} in the

UASB. This equated to a flow of 17 L day^{-1} over each bed. The 30-day experiment was duplicated.

Experimental Scheme 2 (Day 61 to 120). A second pump was added to allow separate recirculation; a pump rate of 600 L day^{-1} equating to an additional 100 L day^{-1} over each leach bed. This matches the hydrolysis experiments by Nizami et al.[17] which effected 70% destruction of volatiles in baled grass silage over a 30-day period. If this destruction of volatiles takes place then methane production should equate to 343 L CH_4 kg^{-1} VS added (assuming 100% UASB efficiency). The existing pump is continued at 100 L day^{-1} generating 0.1 m h^{-1}, the maximum allowable upflow velocity in the UASB; thus total leachate flow rate through each bed was 117 L day^{-1}. The solids loading rate in this period equated to 1.9 kg VS m^{-3} day^{-1}. The organic loading rate in the UASB was 6.46 kg COD m^{-3} day^{-1} (Table 3). This experimental scheme was also duplicated.

2.4. Analytical Methods. DS and VS contents of the input and output grass silage were analyzed using standard methods.[31] Three samples were taken on loading each new batch of silage to the leach bed. Three samples of the digestate from the previous batch were also taken. The average values were used for DS and VS removal calculations during each loading and unloading cycle. The COD concentration of the leachate was measured every second day of digester operation by a COD analyzer (HACH DRB200 and DR/2800, USA). The total volatile fatty acids (TVFA) and alkalinity of leachate were measured once a week using titration-based methods.[32] Before the start up of the experiments, a complete analysis of grass silage was carried out by Agri-Food and Biosciences Institute (AFBI), Northern Ireland and the Irish Agricultural Institute "Teagasc". The C−H−N ratio of grass silage were analyzed by elemental analyzer (CE 440 MODEL) using the ultimate analysis method. The pH of both leachate and UASB effluent was measured digitally every hour using a pH sensor probe (Signet 2754-2757 DryLoc pH/ORP) controlled by the programmable logic controller (PLC) of the system. The measurement of gas flow was carried out on an hourly basis by a digital gas flow meter (FMA-1600A Omega) also controlled by the PLC system. Biogas was analyzed for its composition on a daily basis using a portable biogas analyzer (PGD3-IR, Status Scientific Controls Ltd.). The granules of the UASB were observed at the end of experimental scheme 2 (Day 61 to 120) using an electron microscope (FEI Inspect F). A conductive carbon tap was used at acceleration voltage of 5 kv. The different bacterial types present in the granule were identified based on their morphology using FISH technique.

3. RESULTS

3.1. Process Performance Parameters. *Experimental Scheme 1 (Day 1 to 60)*

- The methane production was 306 L CH_4 kg^{-1} VS added for the first 30-day cycle. This increased to 314 L CH_4 kg^{-1} VS added for the second 30-day cycle. The average is taken as 310 L CH_4 kg^{-1} VS added (Figure 2a).
- With a retention time of 30 days the dry solids removal efficiency varied from 68% to 71%, averaging 69% (Figure 2c).
- The volatile solids removal efficiency varied slightly from 70% to 71%.
- The pH of the leachate varied from 4.5 to 7.0 and averaged 6.0. The pH range of the UASB varied from 6.9 to 7.7 with an average of 7.4. The biological process of the UASB was considered stable (Figure 2e).

Experimental Scheme 2 (Day 61 to day 120)

- With the addition of the second pump methane production increased substantially: to 339 L CH_4 kg^{-1} VS added in the first cycle of 30 days and 344 L CH_4 kg^{-1} VS added in the second cycle of 30 days. The average is taken as 341 L CH_4 kg^{-1} VS added (Figure 2a).
- In the second experimental scheme, the DS removal efficiency increased from 72% to 74%, averaging 73% (Figure 2c).
- The VS removal efficiency increased from 74% to 77% with average value of 75% (Figure 2c).
- The pH of the leachate varied from 4.5 to 7.0, averaging 5.9. The pH of the UASB ranged from 6.8 to 7.7 with an average of 7.4 (Figure 2e). COD removal efficiencies of 90 and 93% were achieved in the first and second experimental scheme, respectively (Figure 2b). During both experimental schemes, the alkalinity of the leachate varied from 340 to 680 mg L^{-1}. The total volatile fatty acids in the leachate varied from 208 to 440 mg L^{-1} (Figure 2d).

3.2. Morphology and Structure of Granule. The average size of granule was found to be 2.55 mm. The granules were dark gray with a spherical shape (Figure 3a). The surface was rough and uneven with irregular projections (Figure 3b). On the surface of the granule, heterogeneous populations of archea were present (Figure 3c). The large nonstaining dark center was seen in the cut cross sectional area of the granule (Figure 3d). Rod-shaped archea (Methanothrix) and cocci-shaped archea (Methanosaricina) were dominant on the granule surface (Figure 3e and g). Filamentous-shaped archea (Methanosaetaceae) were seen in abundance on the granule edges (Figure 3h). Figure 3f indicates round-ended short rod archea (Methanobacterium/Methanobrevibacter) in core and internal layers of the granules.

4. DISCUSSION OF RESULTS

4.1. Stability of Biological Process. The UASB was biologically stable for both experimental periods. The pH in the UASB stayed in the range 6.8−7.7. This is the optimal range as suggested by Tiwari et al.[24] (6.6−7.7) and Kim et al.[33] (6.3−7.8). The pH of the leachate varied from 4.5 to 7.0. This is very close to the range suggested for optimal hydrolysis, e.g., 5−7,[17] 4−6.5,[18] or less than 7.[34]

The observed alkalinity and TVFA of the leachate varied from 340 to 680 and 208 to 440 mg L^{-1}, respectively. For granulation process, the alkalinity and TVFA of the leachate are important.[41] According to Singh et al.,[42] the optimum alkalinity within the influent to the UASB should be in the range 250−950 mg L^{-1}; while the TVFA should be less than 1000−1500 mg L^{-1}.[43]

4.2. UASB Granule Structure and Morphology. The average size of the granule was 2.55 mm. Gupta and Gupta[21] stated that the size of granule is greater than 2 mm when the UASB is fed at high OLR. Larger granules remove COD more efficiently, typically converting 95% of COD converted to methane while the remaining 5% is converted to biomass.[44] The shape of the granules varies with the operating conditions but they usually have a spherical shape[45] (Figure 3a). Large dark centers are noted in the center of the granule as may be noted in the cut cross section of the granule (Figure 3d). This does not agree with the initial theory of a layered structure in the UASB granules.[23] The nonlayered structure of the UASB granule was also observed and reported by Wu et al.[46] According to Fang[47] the nonlayered structure of the granules is due to the rate-limiting hydrolytic or fermentative stage associated with a high protein content. Grass silage has a high protein content (Table 2: 9.5% of DS). Insoluble protein covers the surface of the granule as suspended solids;[48] this results in a "puffy" granule as shown in Figure 3b. The presence of rod-shaped bacteria (Methanothrix) and cocci-shaped bacteria (Methanosaricina) on the granule surface (Figure 3e and g) is in line with the observations of Gupta and Gupta[21] and Bhatti et al.[49] Filamentous-shaped bacteria (Methanosaetaceae) were present in abundance on the granule edges (Figure 3h). According to Li et al.[50] high COD removal in the UASB is the result of the high proportion of filamentous bacteria.

4.3. Methane Content of Biogas. The average methane content during the 120-day experimental period was 70.6%. For grass digestion a value of 55% is typical.[8] This increased level of methane is associated with the two stage system and with the solubility of CO_2; the biogas is passed through a water filter prior to measurement of flows. This increment in methane content is in line with Sawyer et al.[38] and Jung et al.[39] In particular, Jung et al.[39] observed a methane content of 80−90% when the biogas was passed through a weak liquor digestate from a system treating pig slurry.

4.4. Destruction of Volatiles. Hydrolysis rates were good. In a previous work on hydrolysis and leaching (without the UASB) Nizami et al.[17] using the same grass silage found DS and VS removal efficiencies of 70.6% when sprinkling 100 L day^{-1} over each batch. In both experimental periods (with the UASB connected) over 70% destruction of volatiles was effected.

The addition of the second pump increased the DS and VS removal efficiency to 73 and 75%, respectively. The results are in the higher levels as compared with other works such as Ramasamy and Abbasi[35] who observed destruction of VS in the range 37−78% during digestion of various lignocellulosic substrates.

4.5. COD Removal Efficiency. The COD removal efficiency in the UASB efficiency varied between 67.5 to 93%. High efficiency in a UASB is attributed to the constant upflow velocity (<0.1 m $hour^{-1}$), increased influent COD concentration, and high quality granules.[7,40] A constant upflow velocity is required for a good mixing in the UASB. Low upflow velocity results in poor mixing in the sludge bed, while there is a risk of washout of granules at high upflow velocity.[40] The UASB efficiency is increased by increasing the influent concentration.[40]

4.6. Methane Production and Retention Time. The SLBR-UASB was optimized during the second experimental scheme with the separation of flow rates for hydrolysis and upflow in the UASB. The system produced 341 L CH_4 kg^{-1} VS added with 75% removal of VS at a 30-day retention time. This value is practically the same (343 vs 341 L CH_4 kg^{-1} VS added) as that modeled by Nizami et al.[17] based on leaching and hydrolysis tests on the same grass silage. Nizami et al.[7] documented a biomethane potential (BMP) assay on the very same grass silage and got a value of 350 L CH_4 kg^{-1} VS. This indicates that the process is very close to optimal for this grass silage.

The relationship among COD, VS, and CH_4 during the second experimental scheme is shown in Table 3. There is an excellent correlation between the numbers as exemplified below:

Period 1. 70.5% destruction of volatiles @ 1.4 kg COD kg^{-1} VS destroyed with an efficiency of 90% in the UASB generating 350 L CH_4 kg^{-1} COD removed equates to 311 L CH_4 kg^{-1} VS added. The actual value recorded is 310 L CH_4 kg^{-1} VS added.

Period 2. 75% destruction of volatiles @ 1.4 kg COD kg^{-1} VS destroyed with an efficiency of 93% in the UASB generating 350 L CH_4 kg^{-1} COD removed equates to 342 L CH_4 kg^{-1} VS added. The actual value recorded is 341 L CH_4 kg^{-1} VS added.

4.7. Comparison with Scientific Data. These production rates may be compared with values from the scientific literature (Table 1). Asam et al.[36] suggested an upper limit of 361 L CH_4 kg^{-1} VS from grass silage using a BMP assay. Batch tests would indicate values of 280 to 361 L CH_4 kg^{-1} VS. Again it must be stated that the grass silage in these tests is not the same. It is from different countries with different climatic conditions, from different harvests, and different species.

In examining data based on two-stage systems (leach beds followed by high-rate digester) the methane production achieved is high compared to that of Yu et al.[18] and Cirne et al.[19] (165 and 270 L CH_4 kg^{-1} VS added, respectively). Lehtomäki and Björnsson[37] obtained a methane yield of 390 L CH_4 kg^{-1} VS added but at a 50-day retention time. However, 85% total methane (or 330 L CH_4 kg^{-1} VS) was achieved in the first 30 days of digester operation.

The same grass silage was digested in a two-stage wet system complete with recirculation. This achieved 455 L CH_4 kg^{-1} VS added at a retention time of 60 days. With the two-stage system the developer has a choice of lower methane production but at half the retention time of a standard wet system.

4.8. Optimization of a Two-Phase Anaerobic Digestion System Digesting Grass Silage. To optimize a two-phase digestion system it is necessary to maximize the hydrolysis potential which it is suggested is better achieved through separation of the leaching flows from the upflow through the UASB. A UASB tends to operate more efficiently with high-strength liquors; thus a higher solids loading rate associated with a lower retention time may generate more methane per unit of VS than a long retention time, a lower solids retention time, and a weaker liquor.

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