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Biogas from Co-digestion of Sewage Sludge and Microalgae

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Abstract

Microalgae cultivated in waste water could contribute to increased biomass production at municipal waste water treatment plants. The biomass could be utilized for biogas production when co-digested with sewage sludge. In this paper previous published results on co-digestion of sewage sludge and microalgae are summarized and remaining knowledge gaps are identified. The available batch tests in literature mostly concern digestion at mesophilic conditions. Some of those tests indicate a synergetic effect for the co-digestion. Investigations at thermophilic conditions and of semi-continuous processes are scarce. The available results show good possibilities for co-digestion of sewage sludge and microalgae. Further investigations are needed to find optimal conditions for biogas production.

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Keywords: biomass; waste water treatement; batch; continous; BMP; anaerobic digestion

1. Introduction

Among the possible renewable energy sources biomass from microalgae is a promising resource. Compared to other biomass resources the growth rate is high and it can be cultivated without competition to food production on valuable land areas. An attractive process solution for municipal waste water treatment plants is to utilize algae for cleaning the water and in the same time produce biomass that can be used for increased biogas production by anaerobic digestion.

Experimental studies on co-digestion of sewage sludge and microalgae at different conditions including batch test and continuous tests are described in [1-8]. Important issues for a full-scale plant are the possibility to maintain stable operation and optimal biogas production but also the digestate characteristics. The compositions of the substrates are important for achieving stable processes. Too low carbon and nitrogen (C/N) ratio can lead to high ammonia levels that inhibit the production of biomethane [3, 4, 6]. Another factor that can decrease the biomethane production is low availability of the substrates

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for the microorganisms, for example due to large particle size or cell wall resistance [3, 6]. Concerning digestate characteristics, the possibility to dewater the digestate, to recover nutrients (phosphorous and nitrogen) and low levels of metals and other possible harmful substances are important [5-7]. In [2] and [5] it was shown that co-digestion with microalgae enhance the dewaterability of the digestate.

In this paper experiences and results from previous studies on co-digestion of sewage sludge and microalgae both in batch and continuous tests at mesophilic and thermophilic conditions are addressed with special focus on the possibility to increase biogas production. The aim is to summarize and compare the results of previous studies, and identify remaining knowledge gaps.

2. Methods

The paper presents a compilation of significant literature in the area of microalgae as a co-substrate to sewage sludge for biogas production. Batch tests in both mesophilic and thermophilic conditions are included and compared. Possible synergetic effects are in focus and the biochemical methane potential (BMP) for the different co-digested mixtures calculated from the BMP test results of the single substrates are used to evaluate the synergetic effect. The enhanced yield is expressed as the ratio between the difference between the measured and calculated BMP of the mixtures and the calculated BMP obtained from results of mono-digestion of the respective substrate. When the available data allows, the theoretical methane potential is determined based on the content of lipids, carbohydrates and proteins calculated as described in [3]. The conversion efficiency is expressed as the ratio between the measured potential and the theoretical potential. When data for volatile solids (VS) degradation is available the conversion efficiency is instead expressed as the ratio between the amount of VS degraded and VS added.

Results from continuous digestion investigations are also collected and compared. Here the influence of the organic loading rate (OLR) and the hydraulic retention time (HRT) on the biomethane production and process stability are selected as factors for the evaluation.

3. Results

3.1. Characteristics

In Table 1 the characteristics of the substrates used in the different tests are shown. An advantage of co-digestion can be the possibility to achieve a better C/N ratio and better balance of nutrients and of fast degradable carbohydrates and slower degradable proteins and fats as mentioned in [9]. From the characteristics given for the different microalgae and sewage sludge (Table 1) it is not obvious that co-digestion of microalgae and sludge can give those benefits since the C/N ratios and compositions of fats, carbohydrates and proteins are similar. Another possible reason for synergetic effects for co-digestion is better balance of essential trace metals (Se, Co, Mo and Ni) [5, 9]. In [5] it is shown that the microalgae (M3) contain more Co, Mo and Ni than the sludge (S2 and S3).

The second culture of microalgae (M2) is dried. Microalgae 3, 6 and 11 are frozen. Microalgae 10 and Sludge 9 are pre-treated thermally at 120 °C for 40 minutes. All other substrates are not pre-treated.

3.2. Batch tests

The results of the batch tests are presented in Table 2 and 3. The majority of the tests in mesophilic conditions indicate enhanced methane production, with enhancements up to about 20 %, when microalgae and sewage sludge are co-digested. However, the results are uncertain since standard deviations for some of the BMP tests are in the same order of magnitude as the identified enhancement. The highest values of

Table 1. Characteristics of substrates used in the BMP and continuous tests.

Substrate	TS [%]	VS [% of TS]	C/N	Protein [% of TS]	Carbohydrates [% of TS]	Lipids [% of TS]	Ref.
M1-Microalgae 1 (cult. in lw)	4.3	70	9.4	26	36	7	[4]
M2-Microalgae 2 (cult. in mww)	90	65	7.8	26	31	3	[4]
M3-Microalgae 3 (cult. in mww)	8.4	59	5.9	33	35	3	[5]
M4-Microalgae 4 (*Chlorella*)	0.73	81	13.4*	47	-	-	[2]
M5-Microalgae 5 (*Micratinium*)	0.69	76	12.0*	52	-	-	[2]
M6- Microalgae 6 (*Spirulina platensis*)	1.5	50	6	-	-	-	[1]
M7- Microalgae 7 (*Isochrysis galbana*)	0.9-1.0	90	7.1	46	14	20	[6]
M8- Microalgae 8 (Selenastrum *capricornutum*)	0.9-1.0	98	9.2	39	29	30	[6]
M9- Microalgae 9 (*Chlorella vulgaris*)	10.84	79	4.6	55	16	0	[7]
M10- Microalgae 10 (pre-treated M9)	5.41	84	5.7	45	25	0	[7]
M11- Microalgae 11(*Spirulina maxima)*	4.5	86	4.2	-	-	-	[8]
Average and standard deviation		***76 ±14***	***6.7±2****				
S1-Sludge 1 (mixed WAS+ PS)	3.5	77	9.2	25	43	11	[4]
S2-Sludge 2 (WAS)	5.4	73	4.7	49	19	6	[5]
S3-Sludge 3 (PS)	5.5	77	12.7	18	45	9	[5]
S4-Sludge 4 (WAS)	0.74	73	10.3*	-	-	-	[1]
S5-Sludge 5 (WAS)	1.5	61	-	-	-	-	[1]
S6-Sludge 6 (mixed WAS+PS)	3.05	88	-	-	-	-	[6]
S7-Sludge 7 (WAS)	3.98	72	5.5	35	43	0	[7]
S8 – Sludge 8 (PS)	2.96	67	10.0	46	27	0	[7]
S9-Sludge 9 (pre-treated S7)	-	-	-	-	-	-	[7]
S10-Sludge 10 (PS)	4.8	78	14	-	-	-	[8]
Average and standard deviation		***74±8***	***9.4±4****				

cult.= cultivated, lw=lake water, mww= municipal waste water, * COD/N ratio instead of C/N ratio, the values are not included in the average, WAS=waste activated sludge, PS= primary sludge, - = data not available

enhanced methane production are found for the tests (no 2 and 9), where sewage sludge with high BMP values are co-digested with microalgae with low BMP values. This might be due to a higher importance of enhanced hydrolysis of algae biomass by sludge microorganisms, as mentioned in [3], for those cases.

The four different sewage sludge used in the mesophilic tests 1-7 have a BMP of 310 ± 46 Ncm^3 CH_4 gVS^{-1}, the seven different microalgae used in the same tests have a BMP of 236 ± 87 Ncm^3 CH_4 gVS^{-1} and the BMP for the 15 different mixtures co-digested is 318 ± 53 Ncm^3 CH_4 gVS^{-1}, which shows that the variations are rather large.

For the microalgae, the biomethane production decreases in thermophilic conditions compared to the production in mesophilic conditions while sewage sludge digestion result in higher biomethane yields. The majority of the co-digestion tests at thermophilic conditions show negative enhancement values down to about -10%. Also in the thermophilic tests the variations are large with a BMP of 210 ± 78 Ncm^3 CH_4 gVS^{-1} for the microalgae and a BMP of 318 ± 60 Ncm^3 CH_4 gVS^{-1} for the different mixtures co-digested.

3.3. Continuous tests

The results of the continuous tests are presented in Table 4. The working volumes in the continuous

Table 2. Results of batch tests at mesophilic conditions.

Batch test nr	Substrate [% of VS content]	Temp. [°C]	Meas. BMP [Ncm^3 CH_4 gVS^{-1}]	Calc. BMP [Ncm^3 CH_4 gVS^{-1}]	Enhanced yield [%]	Theor. BMP [Ncm^3 CH_4 gVS^{-1}]	Conv. Effi. [%] Meas./ Theor.	Ref.
1	100 % S1	37	331±35	-	-	517	64	[4]
1	88% S1 + 12% M1	37	344±15	335	3	516	67	[4]
1	75% S1+25% M1	37	358±61	350	2	515	70	[4]
1	63% S1+ 37% M1	37	408±17	355	15	513	80	[4]
1	100 % M1	37	367±5	-	-	508	72	[4]
2	88% S1+ 12% M2	37	387±67	313	24	512	76	[4]
2	75% S1+ 25% M2	37	348±65	293	19	508	70	[4]
2	63% S1+ 37% M2	37	325±67	283	15	503	65	[4]
2	100 % M2	37	179±38	-	-	581	31	[4]
3	35% S2 + 65% S3	35	317±2	-	-	595	53	*
3	19%S2 +39% S3+52%M3	35	239±9	235	2	526	45	*
3	100% M3	35	120±2	-	-	585	21	*
4	100 % S4	mesoph.	243	-	-	-	60**	[2]
4	79% S4 + 21% M4	mesoph.	253	240	5	-	56**	[2]
4	100 % M4	mesoph.	230	-	-	-	42**	[2]
5	79% S4+ 21% M5	mesoph.	236	236	0	-	59**	[2]
5	100 M5	mesoph.	209	-	-	-	40**	[2]
6	100 % S6	33	347	-	-	-	-	[6]
6	75 % S6+25% M7	33	318	345	-8	-	-	[6]
6	50 % S6+50% M7	33	356	343	4	-	-	[6]
6	25 % S6+75% M7	33	343	340	1	-	-	[6]
6	100 % M7	33	338	-	-	565	60	[6]
7	75 % S6+25% M8	33	303	312	-3	-	-	[6]
7	50 % S6+50% M8	33	302	278	9	-	-	[6]
7	25 % S6+75% M8	33	254	243	5	-	-	[6]
7	100 % M8	33	209	-	-	624	33	[6]
8	100 % S7	35	80***	-	-	494	-	[7]
8	75 % S7+25% M9	35	92***	87***	5	-	-	[7]
8	50 % S7+50% M9	35	91***	94***	-4	-	-	[7]
8	25 % S7+75% M9	35	107***	101***	6	-	-	[7]
8	100 % M9	35	108***	-	-	460	-	[7]
9	100 % S8	35	266***	-	-	531	-	[7]
9	75 % S8+25% M9	35	252***	227***	11	-	-	[7]
9	50 % S8+50% M9	35	210***	187***	12	-	-	[7]
9	25 % S8+75% M9	35	171***	148***	16	-	-	[7]
10	100% S9	35	95***	-	-	408	-	[7]
10	75 % S9+25% M10	35	103***	115***	-11	-	-	[7]
10	50 % S9+50% M10	35	140***	135***	3	-	-	[7]
10	25 % S9+75% M10	35	152***	155***	-4	-	-	[7]
10	100 % M10	35	176***	-	-	-	-	[7]

* tests described in [5] but data not previously published,** conversion efficiency based on VS degradation, *** the unit for the results are Ncm^3 CH_4 gCOD^{-1}, - = data not available

tests are 5, 7 and 1.5 dm^3 for test 1, 2 and 3, respectively [4, 1, 8]. In the continuous test no 2 a two-stage system is used including one stage of 2 dm^{3}and a second stage of 5 dm^3 [1].

Varol and Urgulu [1] report lower variations in pH for the co-digestion test compared to digestion of the single substrates. This could be due to providing higher buffer capacity when co-digesting with microalgae as observed in [9], where microalgae and corn silage were co-digested. The results from the

Table 3. Results of batch tests at thermophilic conditions.

Batch test nr	Substrate [% of VS content]	Temp. [°C]	Meas. BMP [Ncm^3 CH_4 gVS^{-1}]	Calc. BMP [Ncm^3 CH_4 gVS^{-1}]	Enhanced yield [%]	Theor. BMP [Ncm^3 CH_4 gVS^{-1}]	Conv. Effi. [%] Meas./ Theor.	Ref.
11	100 % S1	55	363±6	-	-	517	70	[4]
11	88% S1+ 12% M1	55	388±75	358	8	516	75	[4]
11	75% 1+25% M1	55	338±65	352	-4	515	66	[4]
11	63% S1+ 37% M1	55	321±15	356	-10	513	63	[4]
11	100 % M1	55	317±53	-	-	508	62	[4]
12	88% S1+ 12% M2	55	323±8	337	-4	512	63	[4]
12	75% S1+25% M2	55	298±55	307	-3	508	59	[4]
12	63% S1+37% M2	55	276±10	281	-2	503	55	[4]
12	100 % M2	55	150±13	-	-	581	26	[4]
13	100 % S6	50	464	-	-	-	-	[6]
13	75 % S6+25% M7	50	420	403	4	-	-	[6]
13	50 % S6+50% M7	50	340	342	-1	-	-	[6]
13	25 % S6+75% M7	50	259	280	-8	-	-	[6]
13	100 % M7	50	219	-	-	565	39	[6]
14	75 % S6+25% M8	50	370	386	-4	-	-	[6]
14	50 % S6+50% M8	50	286	308	-7	-	-	[6]
14	25 % S6+75% M8	50	201	230	-13	-	-	[6]
14	100 % M8	50	152	-	-	624	24	[6]

- = data not available

Table 4. Results of continuous tests.

Cont. test nr	Substrate (% of VS content)	Temp. [°C]	OLR [$kgVSm^{-3}d^{-1}$]	HRT [days]	CH_4 prod. [Ncm^3 dm^{-3} d^{-1}]	Normalized CH_4 yield [Ncm^3 gVS_{in}^{-1}]	CH_4 /VS conv. [Ncm^3 gVS_{red}^{-1}]	Ref.
1	40% S2+60% S3	37	2.5	15	305±55	200±33	393±69	*
			3.5	10	388 ± 39	177 ±21	371±58	
1	22 % S2+51% S3 + 37% M3	37	2.5	15	260 ± 35	172±26	607±165	*
			3.5	10	353 ± 31	158±15	568±62	
2	100% S5	36	0.7**	14	270	386	643	[1]
2	67% S5+ 33% M6	36	0.64**	14	295	461	738	[1]
2	100 % M6	36	0.54**	14	179	332	498	[1]
3	100% M11	35	1.5	20	310	310	733	[8]
			3.0		370	190	725	
			4.5		510	170	688	
			6		620	160	661	
3	9.3% S10 + 90.7% M11	35	3.2	20	690	310	701	[8]
3	32.7% S10+67.3% M11	35	4.4	20	820	280	731	[8]
3	49.4% S10+ 51.6% M11	35	5.8	20	1410	360	748	[8]
3	100% S10	35	2.8	20	640	330	721	[8]

* tests described in [4] but data not previously published,** OLR based on the total volume of the two-stage process.

second and third, but not the first, continuous test indicate a synergetic effect of the co-digestion. However, when the biomethane yield per reduced VS is considered a synergetic effect can be observed also in the first continuous test. The influence of OLR and HRT on the biogas production and process stability cannot clearly be seen. No one of the studies report on any major process instabilities but to better understand the process it is of interest to follow also other parameters than the biogas production, such as volatile fatty acids, ammonia and alkalinity.

4. Conclusions

Available investigations of co-digestion of sewage sludge and microalgae mostly concern batch tests at mesophilic conditions while investigations at thermophilic conditions and of semi-continuous processes are scarce. Synergetic effects of co-digestion of microalgae and sewage sludge at mesophilic conditions are indicated in both batch and semi-continuous tests. The available test results clearly show the possibility for co-digestion of sewage sludge and microalgae. Further investigations are needed to find operation conditions (proportions, loading rates and retention times) for optimal biogas production. For better understanding of the process, more studies following process parameters such as volatile fatty acids, ammonia and alkalinity as well as more analysis of the substrate and digestate composition are needed. In addition, the effect of microalgae implementation on waste water treatment has to be evaluated on a system perspective to identify the total mass balance of substrate, resulting biogas production and nutrient recovery.

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Biography

Eva Thorin is Associate Professor at Mälardalen University and do research at Future Energy Centre. Her research concerns measurements, modeling and simulation of processes and systems for energy conversion with special emphasis on biomass.