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Possibility of Enhancing Methane Productivity in Anaerobic Reactors in the Treatment of Excess Sludge from Wastewater Treatment Plants

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Abstract- This paper describes technological possibilities to enhance methane production in the anaerobic stabilisation of wastewater treatment plant excess sludge. This objective can be achieved by the addition of waste residues: crude glycerol from biodiesel production and residues from fishery. The addition of glycerol in the amount of 2–5% by weight causes the enhancement of methane production of about 250–400%. At the same time, the percentage increase of total solids concentration in the outgoing sludge is ten or more times less. The content of methane in biogas is higher in the case of admixed substrate.

Keywords- *Enhancement of methane production; fishery residues; waste glycerol.*

I. INTRODUCTION

Nowadays, the investigation and use of alternative energy sources have become progressively more topical [1]. Among these sources, biodiesel as a liquid fuel from rapeseed and biogas from the anaerobic digestion of different organic waste are comparatively well known. In general, one of the sources of biogas is the anaerobic digestion of wastewater treatment plant excess sludge. The liquid fuel production also creates waste by-products. One of these is glycerol. Its need for industrial use is limited. The production of 100 kg of biodiesel creates 10–11 kg of waste glycerol [2]. The aim of the investigation was to ascertain how to incorporate ordinary waste sludge and glycerol anaerobic digestion in the best way. Also of interest was whether it is reasonable to use fishery residues in the same manner. Reference [3] claims that concentrated glycerol, as a single raw material, is not treatable by anaerobic digestion technology. Due to the co-substrate effect, glycerol is more easily digested in a mixture of different organic materials where it is in the role of admixture [4].

II. EXPERIMENTAL PROCEDURE

A series of continuous experiments were carried out in order to investigate the influence of glycerol concentration and fish residue on the process. One experiment was performed with raw sludge obtained from Tallinn wastewater treatment plant (WWTP). Other experiments were realised with sludge and additive mixtures, by weight: a) sludge 98% + glycerol 2%, b) sludge 95% + glycerol 5%, c) sludge 98% + fish residue 2%. Glycerol was obtained from the local pilot plant of biodiesel in Estonia (Viljandi). Fishery residues were obtained from the salmon treatment department of Kakumäe fishery near Tallinn, and they were mainly derived from fatty salmon skins and intestines. Digesters with an inner working mass of 1.6, 4.5 and 5 kg were constructed of fibreglass. These were sealed with rubber stoppers and equipped with clamped tubes for influent/effluent. The temperature in the reactors was maintained by water jackets surrounding them, in the case of inner reactive mass of 1.6 and 4.5 kg. The reactor with the inner mass of 5 kg was surrounded by an electric heating pad. The digesters were maintained at a mesophilic temperature (below 40 ^{o}C and above 35 ^{o}C), which was mainly around 36–38 ^{o}C. Mixing was performed with magnetic spinners. That was done every morning before and after feeding. Biogas was collected into a gas clock filled with water and from the level of water the amount of biogas was determined. The reactors were operated in the draw-and-fill mode (on a daily basis) with a retention time of 40 to 20 days. Initially, the reactors were inoculated with anaerobic sludge originating from Tallinn WWTP. Sewage sludge and its mixtures with glycerol were inserted by syringe. The mixture of sludge and fish residue was added through a tube on top of the reactor. The sludge and fish residue was stored in a refrigerator at +4 to +6 ^{o}C until use. The pH was measured by a pH meter (Denver Instrument, UP-5). Everyday sludge removal from the digester took place before feeding the reactor. A gas sample was taken and measured every morning. At first, the amount of gas was determined in the gas clock and then the gas components (CH_4, CO_2, O_2, H_2S and NH_3) were evaluated with biogas analyser (Gas Data GFM416 Biogas Analyser). Once a week, the following was measured: total (TS) and volatile (VS) solids, volatile fatty acids (VFA) and alkalinity (Alk) in the input and output material of the reactors.

III. EXPERIMENTS AND RESULTS

All tests began with a 40 day retention time with the aim to reduce it to 20 days. At the same time, the amount of methane production from digestion matter and the percentage of methane in biogas were measured. Table I below gives the average values of several analyses of substrate used in the experiments. It shows that a small amount of additives may enhance solid concentration by as much as 2.5 times because additive water concentration was very low, i.e. 10.5% in glycerol and 48.2% in fish residue. Among these experiments, raw sludge digestion without an additive (Table II and III) was specified as the standard process. The results obtained in the presence of additives were evaluated and compared with standard process values. The experiments described below reached a stable level on the ninth to twelfth day and on that day the observation of the experiment began. The decision to begin was visually cognitive and based on graphs depicting the biogas and methane production with time. The experiments with 100% sludge and its mixture with glycerol were started on the same calendar day and finished by 82 days. The experiment with the fish additives started later and its effected duration was 29 days (total 55 days). Data were mainly grouped by retention time. To reduce the numerical amount of the data and make them more comprehensive, the average results were evaluated for each group (Tables II, and III).

TABLE I AVERAGE COMPUTATIONAL CONCENTRATION OF DIFFERENT SUBSTRATES USED IN EXPERIMENTS

Substrate	***Total solids (TS), g/L***			***Volatile solids (VS), g/L***		
	Sludge	***Additive***	***Admixture***	***Sludge***	***Additive***	***Admixture***
Sludge 100%	30.85			21.36		
Sludge 98% + glycerol 2%	30.23	17.90	48.13	20.93	16.30	37.23
Sludge 95% + glycerol 5%	29.29	44.75	74.05	20.29	40.75	61.04
Sludge 98% + waste fish 2%	29.99	10.38	40.37	20.27	9.85	30.12

TABLE II DATA FROM SINGLE WASTE SLUDGE DIGESTION BY REACTOR VOLUME 1.7 LITRES

Days considered	***Retention time, days***	***Volume load TS, kg/m^3***	***Input, g/L***		***Output, g/L***		***Organic removal input-output, g/L***	
			TS	***VS***	***TS***	***VS***	***ΔTS***	***ΔVS***
9–21	40	0.89	35.40	26.63	22.38	14.05	13.03	12.63
22–30	35	1.01	35.39	26.62	22.16	13.23	13.23	13.39
31–41	30	1.09	32.64	24.17	22.33	13.82	10.31	10.35
42–55	25	1.05	26.20	16.25				
56–82	20	1.60	32.03	22.38	21.86	13.71	10.16	8.66
Average		1.23	31.97	22.69	22.10	13.73	11.24	10.50

TABLE III CONTINUE OF THE TABLE II

Retention time, days	***Tempe-rature, ^oC***	***Methane yield***		***Methane contents in biogas, %***	***Solid removal, %***	
		Per volume, L/m^3	***TS removed, L/Δkg***		***ΔTS***	***ΔVS***
40	36.5	109.7	339.6	50.98	36.51	47.23
35	37.4	82.1	217.1	51.84	37.40	50.25
30	36.4	92.9	270.3	52.16	31.59	42.81
25	38.5	117.9		54.51		
20	37.9	171.5	337.24	57.59	31.75	38.68
Average	37.2	128	310.9	54.39	33.55	42.95

In these tables, the last row presents the weighted average values. Due to the absence of essential information on some values, the data about pH, alkalinity, volatile fatty acids and impurities (H_2S, NH_3) are not considered. Likewise, in tables II and III, the data of other experiments were computed. These include: sludge with 2% glycerol (reactive mass 1.6 kg), sludge with 5% glycerol (reactive mass 5.0 kg) and sludge with 2% fish residues (reactive mass 4.5 kg).

Detailed tables about the mixtures are not presented and only the last rows presenting weighted averages are shown in tables IV and V. The bracketed values are minimums and maximums considering the weighted average.

TABLE IV THE SUMMARISED DATA OF THE EXPERIMENTS ON THE LEVEL OF WEIGHTED MEANS

Substrate	***Days considered***	***Retention time, d***	***TS input, g/L***	***VS input, g/L***	***TS output, g/L***	***VS output, g/L***	***ΔTS, g/L***	***ΔVS, g/L***
Sludge 100%	73	27.6	32.0 (26.2–35.4)	22.7 (16.3–26.6)	22.1 (21.9–22.4)	13.7 (13.2–14.1)	11.2 (10.2–13.2)	10.5 (8.7–13.4)
Sludge 98% + glycerol 2%	69	31.0	49.3 (44.9–52.8)	38.8 (34.6–42.4)	24.6 (23.0–30.7)	13.3 (9.5–17.9)	24.7 (21.7–29.6)	24.6 (16.2–27.9)
Sludge 95% + glycerol 5%	70	35	64.0 (58.2–77.3)	58.6 (48.8–64.1)	27.0 (23.5–32.3)	15.1 (10.8–19.0)	44.5 (34.4–53.8)	43.7 (38.0–50.7)
Sludge 98% + fish 2%	29	35.7	43.0 (40.4–46.8)	32.4 (30.2–34.8)	23.8 (21.5–24.6)	14.0 (12.8–15.0)	20.8 (18.9–22.6)	18.4 (17.4–19.9)

Visual examination of tables II and III and unrevealed tables present the main drift:

1. Decreasing the retention time increases the volume loading, and the methane production per volume unit of the reactor. Here, the volume of the reactor means the volume of the reacting mass in the reactor.
2. It is evident that organic matter removal in anaerobic digestion mainly takes place via the volatile organic matter and therefore the percentage removal of volatile solids as bio digestible is higher than total solids.
3. In the same experiment, the concentration values of input, output and removed organics vary around the average or median and they may be considered as stable.

Summarizing the results of tables IV and V points towards the following conclusions:

1. Admixed sludge has a higher volume load and higher concentration numbers.
2. The difference between the input output concentrations are more directly interconnected with the volume load and the concentration of output solids is influenced less.
3. Anaerobic digestion of admixed sludge produces biogas with a higher methane concentration.
4. A higher volume load gives a higher methane yield, but the yield per removed organics varies around a mean value.
5. Methane production is increased by additives more than the remaining solid residue in outgoing sludge or pulp.
6. The admixture from fishery has a higher potential to increase methane productivity than glycerol addition.

TABLE V CONTINUE TABLE IV

Substrate	***Methane yield***		***Methane contents in biogas, %***	***Solid removal, %***	
	Per volume, L/m³	***Per removed TS, L/Δkg***		***ΔTS***	***ΔVS***
Sludge 100%	128 (82–172)	310.9 (217–340)	54. (51–57.6)	33.6 (31.6–37.4)	43 (38.7–50.3)
Sludge + 2% glycerol	323 (269–537)	381.9 (338–455)	61.4 (60.1–62.7)	50.1 (41.9–56.3)	66 (65.1–75.1)
Sludge + 5% glycerol	488.6 (234.9–705.3)	386.1 (273.1–530.4)	59.3 (57–61.6)	62 (54.7–69.6)	74.3 (68.1–77.9)
Sludge + 2% fish residues	369.4 (328.9–419.5)	627.7 (582.6–686.2)	63.5 (62.4–64.9)	48.5 (46.7–50.7)	56.8 (55.8–57.7)

Table VI was derived on the basis of tables IV and V. It compares the influence of additives to methane productivity. Methane production increased up to about 400% without a remarkable increase of residue solids in output sludge. This shows how to use existing anaerobic facilities of wastewater treatment plants for the production of alternative and green energy.

TABLE VI COMPARISON OF WEIGHTED MEAN RESULTS (IN BRACKETS) AGAINST SINGLE SLUDGE DIGESTION

Substrate	***Detention time in days***	***Percentage relations***		
		TS load per reactor volume	***Solids residue after treatment***	***CH_4 productivity per reactor volume***
Raw sludge 100%	40–20	100 (1.23)	100 (22.1)	100 (128)
Sludge + 2% glycerol	40–20	164 (2.02)	111.3 (24.59)	252 (323)
Sludge + 5% glycerol	40–20	173.1 (2.12)	122.1 (26.99)	382 (488.6)
Sludge + 2% fish residues	40–30	99 (1.22)	107.9 (23.84)	288.6 (369.4)

IV. CONCLUSION

1. The yield of methane production of existing anaerobic reactors can be efficiently enhanced by adding glycerol or fishery residues. Methane concentration in the biogas is also higher.

2. Both additives are industrial waste. Their utilization is an environmentally desirable process. By adding waste glycerol 2–5% by weight, the methane productivity per volume of the reactor increased around 250–400% and by adding fish residue 2% by weight, the methane productivity per volume of the reactor increased about 290%.

3. The increase of methane production by additives is more than ten times higher than the increase of solid residues in the outgoing sludge.

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