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Enhancement of Methane Productivity of Anaerobic Reactors of Wastewater Treatment Plants

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Abstract**—**This paper describes technological possibilities to enhance methane productionin the anaerobic stabilization 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 ofglycerol in an amount by weight of 2 – 5% causes 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 containment of methane in biogas is higher in case of admixed substrate.

Keywords**—**Enhancement of methane production,fishery residues,waste glycerol

I. Introduction

NOWADAYS the investigation and use of alternative energy sources has becomemore and more topical[1].Among these sourcesbiodiesel as a liquid fuel from rape seed and biogas from anaerobic digestion of different organic waste is comparatively well-known.In generalone of the sources of biogas is anaerobic digestion of wastewater treatment plant excess sludge. The liquid fuel production createsalso waste by-products.One of these is glycerol. Its need for the industrial use is limited. The production of 100 kg 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 waswhether it is reasonable to use fishery residues in the same manner. Reference material [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 organicmaterials where it is in the role of admixture [4].

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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 carried out with raw sludge obtained from Tallinn wastewater treatment plant (WWTP). Other experiments were carried out with sludgeand additive mixtures, by weight: a) sludge98% + 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. Temperature was maintained by water jackets surroundings the reactors with an 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. Temperature of the digesters was kept mesophilic (below 40 ^{o}C and above 35 ^{o}C) and around 36 - 38 ^{o}C. Mixing was effected with magnetic spinners. Mixing was done every morning before feeding and after feeding. Biogas was collected into a gas clock which was filled by water and from the level of water the amount of biogas was determined. The reactors were operated in 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 the Tallinn WWTP. Sewage sludge and its glycerol mixtures were inserted by syringe. Mixture of sludge and fish residue was added through atube on top of the reactor. The sludge and fish residue was stored in 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 digester took place before feeding the reactor. 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 reactor.

III. Experiments and Results

All tests started with a 40 day retention time. The aim was to reduce retention time to 20 days, and identifythe amount of methane production from digestion matter and the percentage of methane inbiogas.Small amount of additives enhancedsolid concentration by as much as 2.5 times because additive water concentration was very low, 10.5% in glycerol and 48.15% in fish residue. Among these experiments the raw sludgedigestion without an additive (Table I and II) was specified as the standard process.

TABLE I
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	0.885	35.4	26.625	22.375	14.05	13.025	12.625
22 - 30	35	1.011	35.394	26.62	22.159	13.234	13.234	1338.8
31 - 41	30	1.088	32.644	24.169	22.331	13.819	10.313	10.35
42 - 55	25	1.048	26.203	16.25				
56 - 82	20	1.601	32.025	22.375	21.863	13.713	10.163	8.663
Average		1.227	31.972	22.693	22.1	13.728	11.242	10.504

TABLE II
CONTINUE OF THE TABLE I

Retention time days	Tempe-rature^{o}C	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

TABLE III
THE SUMMARISED DATA OF THE EXPERIMENT SON THE LEVELOF 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)

TABLE IV
CONTINUE TABLE III

Substrate	Methane yield		Methane contents in biogas %	Solid removal %	
	Per volume ,L/m^3	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 V
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 (1,227)	100 (22.1)	100 (128)
Sludge+2% glycerol	40 - 20	164 (2.016)	111.3(24.588)	252 (323)
Sludge+5% glycerol	40 – 20	173.1(2.124)	122.1(26.994)	382 (488.6)
Sludge+2%fish residues	40 - 30	99 (1.215)	107.9(23.836)	288.6(369.4)

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 – 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 single sludge and its mixtures with glycerol were started at a same day and finished by 82 days.The experiments with fish additives started later and its considered duration was 29days (total 55 days). Data were grouped mainly by retention time. To reduce the numerical amount of the data and make them more comprehensive, the average results were evaluated for the groups (Tables I, and II).

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 I and II, the data of other experiments were computed. These include: sludge + 2% glycerol (reactivemass1.6 kg), sludge + 5% glycerol (reactive mass 5.0 kg) and sludge + 2% fish residues (reactive mass 4.5 kg).

To keep the size of this paper down the tables about the mixtures are not presented and only the last rows presenting weighted averages are shown in tables III and IV. The bracketed values are minimum and maximum considering weighted average.

Visual examination of these, hereby unrevealed, tables gave the main drift:

1. Decreasing the retention time increases the volume loading, and the methane production per volume unit of the reactor. Hereby, 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 takes place mainly via the volatile organic matter and therefore the percentage removal of volatile solids as biodegradable is higher than total solids.
3. In the same experiment the concentration values of input, output and removed organics are varying around the average or medium and they may be considered as stable.

The summarising and generalising (Tables III and IV) point 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 volume load and 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 was derived on the basis of tables III and IV. It compares the influence of additives to methane productivity.

Methane production increased nearly up to 400% without a remarkable increase of residue solids in output sludge. This evidence shows how to use existing anaerobic facilities of the wastewater treatment plants for the production of alternative and green energy.

IV. Conclusions

1. The yield of methane production from anaerobic excess sludge reactor scan be enhanced efficiently by adding glycerolor fishery residues. Methane concentration in the biogas is also higher.
2. Both additives are industrial waste. Their utilisation is environmentally a desirable process. Adding waste glycerol 2 – 5% by weight, the methane productivity per volume of reactor increased around 250 – 400% and adding fish residue 2% by weight, the methane productivity per volume of 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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