GENERALISED INTEGRATION OF SOLID WASTE TREATMENT PRACTICES TO ENHANCE METHANE PRODUCTIVITY, GENERATE SUSPENSION FERTILISER AND UPGRADE BIOGAS

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Abstract

This paper presents a general solution of how to link together the treatment of different solid waste: excess sludge, wastes glycerol or fishery residues and waste ash. The aim of the solution is to enhance biogas production and to produce an organic–mineral suspension fertiliser. The enhancement of biogas productivity is achieved by adding waste glycerol from biofuel plants or fish residues from fish farming and fishing industries into anaerobic reactors of wastewater treatment plants. The enhancement of biogas productivity lies in the range of 200–400%. The fertiliser is produced as a mixture suspension on the basis of waste sludge, waste ash and mineral fertilisers. The mixture is treated by mechanical disintegration, which is responsible for homogenisation and dehelminthing. If the pH of the suspension fertiliser must be reduced, the bubbling of biogas through the suspension can be used. The carbon dioxide content is diminished and the calorific value of the biogas is elevated.

Keywords: Excess sludge, ash, waste glycerol, disintegration, suspension fertiliser, biogas enhancement and upgrading

Introduction

This article gives an overview on how to implement the integrated treatment of different solid wastes: wastewater treatment plant (WWTP) excess sludge, waste glycerol from biodiesel production, fishery residues, and oil shale fly ash from electric power stations. The objective was to find the best way to deal with the particular waste management problem and to generate usable products.

The waste glycerol used in anaerobic degradation is today one of the sources of alternative energy (Mousdale, 2008; Kuusik *et al*., 2012). Biodiesel production creates 10–11kg waste glycerol per 100 kg biodiesel (Miele *et al.,* 2008). The aim of the investigation was to ascertain best way to incorporate ordinary waste sludge and glycerol into anaerobic digestion. It was also of interest whether fishery residues could be used in the same manner. Hutňan (2009) 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 an admixture (Fountoulakis, 2010; Kaosal *et al.*, 2012).

The solution to this problem causes another problem of how to use the remaining sludge. The proper method is to produce suspended fertilisers on the bases of stabilised waste sludge and waste fly ash, which can be linked together with mechanical disintegration.

Suspension fertilisers are mixtures of liquid, stabilisation matter, and dissolved and non-dissolved mineral nutrients. Stabilisation material commonly has a clayish nature and its purpose is to hold the non-solute fertiliser particles homogeneously in suspension. Clay or similar matter is generally substitutable by non-settle able excess sludge that originates from activated sludge treatment (Loit H., 1989). The sludge content of dry solids has to be around 4% (≥40g L^{-1}) and may reach (6–8%). When excess sludge and shale ash are used together in the mass, the concentration of sludge may be less (Sokk *et al.*, 2007). Even 20 g L^{-1} may be sufficient.

The waste sludge must not contain viable helminth eggs. If required, the dehelminting process can be carried out by mechanical disintegration.

The disintegrator (Hint, 1981) is a mill where opposing discs are equipped with milling elements (Figure 1) positioned in intermeshing circles. The material to be ground is directed to the centre. A centrifugal force carries the material outward through the counter-rotating milling elements. The collision velocity between material particles and the milling elements depends on the rotating speed and element placement radius and may reach 300 m s^{-1}. It was expected that helminth eggs would be damaged and lose germinating ability in such a highly energetic mechanically agitating environment. Such treatment is not sufficient to decrease the viability of infectious bacteria; therefore, separate treatment to degrade bacterial germinating is needed. Utilisation of shale ash in the mixture of_suspension fertilisers raises the pH level and that in turn suppresses the viability of the micro flora.

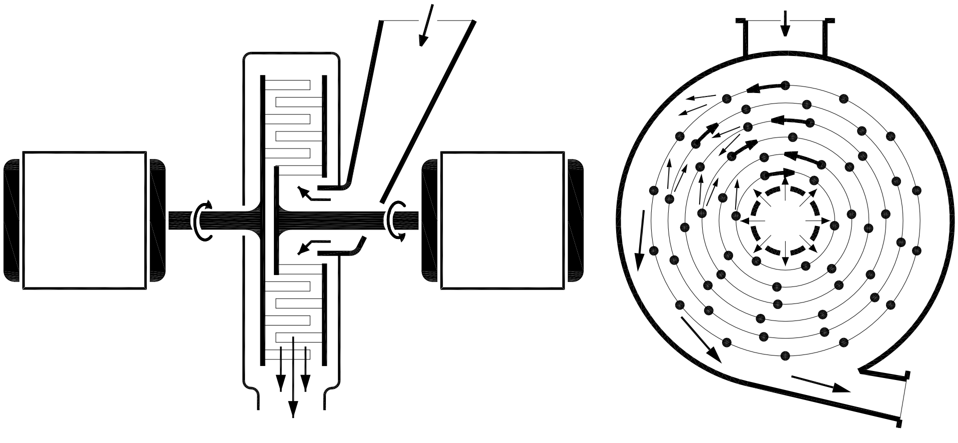

Figure 1 The schematic construction of disintegrator: side view on the left; treatment process on the right (according to Hint, 1981).

I. Experimental procedure

1. Anaerobic degradation

A series of continuous experiments were carried out in order to investigate the influence of glycerol and fish residue concentrations on the process. One experiment was performed with raw sludge obtained from Tallinn WWTP). Other experiments were performed 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 biodiesel pilot plant in Estonia (Viljandi). Fishery residues were obtained from the salmon treatment department of Kakumäe fishery near Tallinn. 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 transmission. The temperature in the reactors of inner reactive mass of 1.6 and 4.5 was maintained by using water jackets surrounding them. The reactor with the inner reactive mass of 5 kg was surrounded by an electric heating pad. The temperature of the digesters was kept mesophilic (between 35 and 40 ^{o}C), mainly around 36–38 ^{o}C. Mixing was effected with magnetic spinners. That was done every morning before 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 the draw-and-fill mode (on a daily basis) with a retention time of 20 to 40 days. Initially, the reactors were inoculated with anaerobic sludge originating from Tallinn WWTP. Sewage sludge and its mixtures with glycerol were inserted by syringe. A mixture of sludge and fish residue was added through a tube on the top of the reactor. The sludge and fish residue was stored in a refrigerator at +4 to +6 ^{o} C. The pH was measured by a pH meter (Denver Instrument, UP-5). Each day, sludge removal from the digester took place before feeding the reactor. A gas sample was taken and measured every morning. 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 determined with biogas analyser (Gas Data GFM416 Biogas Analyser). The methane yield of an anaerobic process depends on the amount of organics (represented by VS content) and the biochemical characteristics of the organics (Zheng *et al.*, 2013). 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.

2. Preparing suspension fertilisers

Pilot plant dehelminting experiments were carried out in Uzbekistan on a disintegrator of 1.2 m rotor diameter and a rotation speed 1500/1500 min^{-1} (impact velocities ≤ 185 m s^{-1}). Local specialists in the laboratory of the Tchirchik WWTP counted the helminth eggs in one litre samples. The method was known and accepted at that time in the former USSR. In a highly concentrated salt solution, the eggs float to the liquid surface from where they are gathered and countered under a microscope. Infection tests on guinea pigs were accomplished in the Hygienic Institute in Samarkand.

Experiments to reduce the concentration of viable intestine micro-flora were carried out in Tallinn University of Technology on a 35 cm rotor diameter disintegrator at a rotation speed of 3000/3000 min^{-1}, which gave an impact velocity 110 m s^{-1}.). The concentration of viable intestine micro flora was determined as the number of CFU (colony formed units) per one gram of suspension. This number was determined for *Escherichia coli* as the representative of intestine micro flora and indicator of contagiousness. CFU was measured by the most probable number method in the microbiology laboratory of the Estonian Environmental Research Centre. The value of the pH was determined by measuring the sludge water solutions (1:5).

A number of tests of interacting between suspension fertilisers and biogas were carried out in a hermetically closed plastic bottle; biogas and suspension fertilisers were introduced into the bottle. These components were shaken for 3–5 minutes. The bottle had a hose connection with a vessel containing liquid or suspension. It was necessary for the elimination of the vacuum created by absorbed CO_2 in the bottle. Biogas was obtained from an anaerobic reactor treating the liquid wastes of a yeast factory.

II. Experiments and results

1. Anaerobic degradation with mixtures

All the tests started with a 40 day retention time. The goal was to reduce the time to 20 days. At the same time, the amount of methane production from digestion matter and the percentage of methane in biogas were measured. Among these experiments, the raw sludge digestion without an additive (Table 1 and 2) was specified as the standard process. The result obtained in the presence of additives were evaluated and compared with the 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 experiments with 100% sludge and its mixture with glycerol were started on the same calendar day and finished in 82 days. The experiment with the fish residue started later and was observed for the duration of 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 1, and 2).

Table 1 data from single raw waste sludge digestion by reactor volume 1.7 litres

Days considered	***Retention time, days***	***Volume load TS kg/m^3/d***	***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	13.388
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 2 data from single waste sludge digestion reactor volume 1.7 litres (continuation of Table 1)

Retention time days	***Temperature °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

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 shown.

Similarly as tables I and II, 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).

These tables about the mixtures are not presented and only the last rows presenting weighted averages are shown in tables 3 and 4. The bracketed values are minimums and maximums regarding weighted average.

Table 3 summarised data according to weighted means

Substrate	*Days considered*	*Retention time, d*	*TS input, g/L*	*VS input, g/L*	*TS output, g/L*	*VS output, g/L*	*∆TS, g/L*	*∆VS, 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)

Summarising the results of tables 3 and 4 against the data of Table 1 points towards the following conclusions:

1. Admixed sludge has a higher volume load and higher concentration.
2. The difference between the input output concentrations are more directly related to 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; the yield per removed organics varies around a mean value.
5. Methane production is increased by additives more than the production of 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 4 summarised data according to weighted means (continuation of Table 3)

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 98% +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 95% + 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 98% +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 5 was derived on the basis of tables 3 and 4. It compares the influence of additives on methane productivity. Methane production increased up to about 400% without a remarkable increase of residue solids in output sludge. This shows how to use the existing anaerobic facilities of WWTP for the production of alternative and green energy.

Table 5 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)

2. Suspension fertilisers

Technology for the production of suspension fertilisers with excess sludge as the stabilising matter was developed in the years 1986–1990 and put into pilot scale use in Central Asia. However, the sludge had a very high concentration of helminth eggs (hundreds per litre). Mechanical disintegration was investigated for the dehelminthing of sludge.

Experiments without mineral nutrients were carried out in excess sludge solid concentrations of 2–4% and with minerals in concentrations of 6–10%.

The results of sludge dehelminting experiments for a throughput of 5 m^3 h^{-1} are summarised in Table 6 (Loopere *et al.,* 1987). A detailed description of their technical specifications is not the goal of this article. We see that complete dehelminting is available when disintegration is carried out in a blend of sludge and mineral fertilisers.

Table 6 Characteristics of experiments.

Varia nt	***Type of rotor***	***Material treated and dry solid content in sludge***	***Efficiency of dehelminthing, %***	***Specific energy consumption, kJ kg^{-1}***
1	Blade	Sludge 2–4%	88	72
2	Blade	Sludge 6–8% and minerals	100	72
3	Blade densified	Sludge 2–4%	96	60
4	Blade densified	Sludge 6–8% and minerals	100	60

Parallel fertilising trials with the same quantity of mineral nutrients, in one case as dry solid and in the other case in suspension, were accomplished. In Uzbekistan, on-field productivity increase was in the range of 3–9% in the case of onion, tomato and maize cultivation. A few samples from sludge containing 15–25 % helminth eggs after treatment were sent to the laboratory to investigate the viability of the remained eggs. Infection tests on guinea pigs showed that the eggs of untreated sludge had infectiousness of over 90%. Untreated sludge had lost this capability (Loit *et al.,* 1989).

New experiments to create suspension fertilisers, based on non-stabilised wastewater treatment sludge, were launched in the autumn of 2006 in Tallinn (Sokk *et al*., 2007). Oil shale ash, obtained from a thermal power station, was used for the stabilisation of the waste sludge and the reduction of intestine micro flora. At the present time, there are no emerging problems with helminth eggs in high income countries (Jimenez, 2011); moreover, the complete neutralisation viability of helminth eggs is achieved in a lime environment (Jimenez-Cisneros, 2007). In Tallinn wastewater sludge, only single eggs in a few sludge samples have been discovered and the regulation allowing an average permissible number of one helminth eggs per litre is being met. The concentrations of heavy metals in sludge and ash were considered. In principle, it was revealed that their mixture could be used as fertiliser because the concentration of heavy metals is not significant (Table 7). Therefore, the objective of the experiments was how to reduce the number of *Escherichia coli* (Table 8). The permissible number of CFU for *Escherichia coli* is no more than 1,000 per 100 ml sludge suspension. This enables to indicate the sludge to be innocuous.

Table 7 Concentrations of heavy metals in dry solids, mg/kg.

Metal	*In sludge*	*In ash*[1]	*In mixture*[2]	*Permissible in sludge****
Cd	0.73–6.0	0.19–3.5	≤ 4	20
Cu	41–700	5.6–17.9	≤ 132	1,000
Ni	6.0–200	19	≤ 50	300
Pb	5.0–98	13.4–383	≤ 340	750
Zn	181–1120 724–3933[3]	284	≤ 425	2,500
Hg	0.1–1.7	1	≤ 1.2	16
Cr	4.9–180 126–3995[3]	15.5–58.6	≤ 80	1,000

[1]Häsänen, et al (1997)
[2]Calculated as maximum for dry mixture that is derived from raw mixture with 40% dry ash and 60% raw sludge containing 8% dry solids
[3]These extreme concentrations are measured only by Keila WWTP (Estonia).

Table 8 CFU g^{-1} of *Esherichia coli* in suspensions.

Mixture	*CFU measured*		*pH*	*Dry solids %*	*Experiment*
	Day of disintegration	*After 3 days*			
Natural sludge	3,155,354		7.11	6.63	First
Natural sludge disintegrated	13,220,556		7.25	4.67	
Mixture (sludge 60%, mineral fertiliser 40%) disintegrated	18,071	11,556	5.65	41.5	
Mixture (sludge 60%, fertiliser 32%, ash 8%) disintegrated	54,361	11,556	6.86	41.5	
Natural sludge disintegrated	19,259,046		6.91	6.5	Second
Mixture (sludge 60%, fertiliser 20%, ash 20%) disintegrated	15,196		8.36	37.7	
Mixture (sludge 60%, fertiliser 10%, ash 30%) disintegrated	198		9.19	41.9	
Mixture (sludge 60%, ash 40%) disintegrated	<12.3		12.26	45.5	

The calculated CFU in raw sludge of the two last versions in Table 8 gives 8,300 and <560 per 100 ml respectively.

On the basis of Table 8, the following conclusions can be drawn:

1. Disintegration is not a diminishing factor for CFU number in waste sludge.
2. Prolonging the contact time between the sludge mixture components diminishes CFU.

3. The main-diminishing factor of the CFU in the sludge mixture is a pH of over 12. With that, the required CFU number is achieved.

It was concluded that disintegration of the sludge with mineral fertilisers has a great impact on dehelminthing but not for the sanitation in regard to intestine bacteria. Sanitation is achieved by increasing the sludge mixture pH. Preparing the fertiliser mixture and its disintegration was accomplished simultaneously. The process was completed in about half an hour. Table 8 indicates both that the presence of mineral fertilisers decreases the mixture pH and that only comparatively high ash concentrations can increase it. Tests to reveal the influence of the ash concentration and its contact time to pH value without fertilisers are presented in Table 9.

Table 9 CFU g^{-1} of *Escherichia coli* in the mixture of waste sludge and shale ash.

Ash %	***CFU measured***		***pH***	***Dry solids %***
	After 1 day of contact time	***After 4 days of contact time***		
Natural sludge	214,720	50,384	6.81	2.17
2.5	240,800	4582	8.99	5.29
5	621	925	10.58	6.72
10	23	<5.6	11.58	12.4

Different mineral fertilisers were added to sludge, which contained 10% ash and had been in contact for 4 days. A fertiliser concentration of 20% was maintained in the suspension. From these mixtures, the CFU of *Escherichia coli* was measured. The results are presented in Table 10.

Table 10 CFU by different fertiliser suspensions.

Fertiliser	***Dry solids %***	***pH***	***CFU g^{-1}***
Ammonium nitrate	29.8	7.43	<5.6
Sodium nitrate	30.8	10.59	<5.6
Superphosphate	28.5	6.63	<5.6

Table 5 indicates that chemical processes took place in the mixture of sludge, as every mineral fertiliser caused a different pH. This phenomenon would have no influence on CFU if the contact time between ash and sludge had been sufficient before the fertilisers were added. Here, all CFU stayed under the determination threshold.

Primarily, the decrease of the pH takes place in the mixture containing NH_4^+ ions. When they are absent (for instance sodium nitrate in our case), the falling of pH is insignificant. Therefore, the neutralisation of the fertiliser suspension is recommended.

When the pH of the suspension is too high, it is possible to decrease it by bubbling biogas through the suspension.

In the contacting tests, the initial volume ratio of the biogas and suspension fertiliser was 4:1. The nutrition component in the suspension was sodium nitrate ($NaNO_3$) in a mass concentration of 20% and ash concentration of 10%. The average values of the three repeated tests were:

1. The concentration of CH_4 increased from 57% to 93.5% with a variation of <3%.
2. The pH of the suspension fertiliser dropped from 12.23 to 10.05.
3. By smelling, the concentration of hydrogen sulphite (H_2S) and other malodorous components was obviously decreased. Instrumental analysis didn't show the presence of H_2S.
4. When treated suspension fertilisers with a pH of 10–11 were bubbled again (under previous conditions), the pH continued to drop and the new value was 7.2–7.5.

Discussion

Electric power production based on the combustion of oil shale results in large-scale formation of lime-containing ash and a high CO_2 emission in flue gases (carbon emission is as high as 29 tons per TJ of produced energy) (Kuusik *et al.*, 2005; Kuusik *et al.*, 2005). The possibility of using ash in the process of oil shale combustion to capture the carbon dioxide contained in the flue gases was investigated (Uibu *et al.*, 2007). Waste ash suspension in water was prepared and flue gases were bubbled through it. Satisfying results for the absorption of CO_2 in ash suspension were obtained (Uibu *et al.*, 2009). This phenomenon is closely related to the suspension pH, and the pH drops in the process of CO_2 absorption (Uibu *et al.*, 2010). This knowledge encouraged us to examine this principle in regard to suspension fertilisers, where the source of CO_2 is biogas (Sokk *et al.*, 2008).

In view of this, it is clear that lowering the pH by means of biogas will cause its purification and increase its calorific value (Mostbauer, 2008; Lombardi *et al., 2008*). This linked together with suspended fertiliser production can be regarded as a method for biogas upgrading for use as a consumable energy carrier. In this case, biogas productivity becomes important and it is reasonable to treat liquid wastes of high organic concentration anaerobically. Wastewaters from different food production industries have high BOD and COD concentrations. We have anaerobically tested wastewaters originating from cheese and vegetable oil production and alcohol distilleries (Blonskaja *et al.*, 1999; Blonskaja *et al.*, 2006).
A short review of these experiments is presented in table 11.

Table 11 The main investigated parameters of the anaerobic treatment processes.

Reactor type	***Origin of wastewater***	***HRT days***	***Load, kg COD $m^{-3}d^{-1}$***	***COD input***	***COD removal %***	***Energy produced kJ/ $m^{-3}d^{-1}$***
Contact process[0]	Cheese whey	5–10	4.32–18.28	60 300–66 700	40–83	78.2
UASB[0]	Cheese whey	2.5–12	0.5–16		58–98	72.4
Fixed bed[0]	Distillery	10–19	2.5–5.1	49 000–53 000	≤54	≤23.1
UASB[0]	Distillery	20–39	0.6–2.5		≤93	≤16.2
Fixed bed[0]	Vegetable oil	7–90	0.1–2.2	6 700–11 000	≤85	≤11
Fixed bed[1]	Vegetable oil	1–1.5	6–9		≤85	≤71.7
Fixed bed[2]	Vegetable oil	3–4	1.6–2		≤85	≤17.2

[0]Single stage reactor
[1]First stage anaerobic reactor
[2]Second stage anaerobic reactor

Considering the average values of the 4th and 6th columns in Table 11, the 7th column for potential energy production is created. In this, the facts that one kg CH_4 corresponds to four kg COD and combustion (oxidising) of one kg CH_4 produces 50 kJ energy were taken into account (Mitzlaff, 1988). In these calculations, it was assumed that 10% of COD removal was caused by anaerobic biomass synthesis (Olvera *et al.*, 2012). COD removal in the case of cheese whey was calculated on the basis of median values of COD.

The stored potential energy of refined biogas (97% methane) is 9.67 kWh/m^3 and of natural gas is 11.0 kWh/m^3. They are equivalent to about 1.1 and 1.2 litres of petrol accordingly (Swedish Gas Technology Centre, 2007). The production cost of biogas energy can be about 2.5–6 times cheaper than the retail cost of fossil energy (Technical Note No. 1, October 2007).

In principle, it is possible to use excess sludge with waste admixtures; with waste ash, biogas production is enhanced, mineral organic suspension fertiliser is obtained and biogas as an alternative energy carrier is upgraded. An advantage of this is also that by bubbling with biogas a part of the CO_2 that is released earlier is captured as carbonates and the “greenhouse effect” is retarded. In the above-mentioned waste treatment technologies, the only marketable material used is real mineral fertiliser.

The used tests demonstrate the possibilities and ways for resolving problems related to the reduction of environmental pollution. On the basis of the above presented experiments and cited literature sources, some general methods to direct excess sludge from WWTP into soil as fertiliser can be devised:

A. The use of stabilised sludge for horticulture and/or agriculture when heavy metal containment is in the permissible range and helminths or/and microbial infection danger is absent or is not a problem.

Input: excess sludge and glycerol or fishery waste.

Process: anaerobic degradation of sludge with additives.

Output: increased amount of biogas produced and stabilised sludge as raw material for bio solids.

B. The use of stabilised sludge for horticulture or/and agriculture when heavy metal concentration is in the permissible range and dehelminthing or/and sanitation is needed.

Input: excess sludge, glycerol or fishery waste, mineral fertilisers.

Process: 1. Anaerobic degradation of sludge with additives.

2. Making a mixture of stabilised sludge and ash and holding it ≥ 4days.

3. Neutralising of alkali mixture of sludge and ash via bubbling of biogas through the mixture.

Output: Increased amount of refined biogas where methane contents may be over 90%. Dehelminthed and stabilised sludge may be regarded as biosolid.

C. The use of stabilised sludge in the composition of suspended fertilisers for horticulture or/and agriculture when heavy metal concentrations are in a permissible range, dehelminthing is needed and sanitation is not needed or is not a problem.

Input: excess sludge, glycerol or fishery waste, mineral fertilisers.

Process: 1. Anaerobic degradation of sludge with additives.

2. Preparing a mixture of anaerobically treated sludge and mineral fertilisers.

3. Disintegration the mixture of sludge and mineral fertilisers.

Output: increased amount of biogas produced and dehelminthed-stabilised suspension fertiliser.

D. Production of suspension fertilisers using stabilised excess sludge. Microbial sanitation is needed

Input: Excess sludge, glycerol or fishery waste, ash which creates pH ≥ 12 in water

Process: 1. Anaerobic degradation of sludge with additives.

2. Mixture of stabilised sludge, and ash that is held ≥ 4 days before disintegration.

3. Disintegration of mixture with mineral fertilisers.

4. Neutralising of alkali mixture of sludge, ash and mineral fertiliser via bubbling of biogas through the mixture

Output: refined biogas, where methane content may be over 90%, dehelminthed and sanitised sludge as bio solid.

E. The use of suspension fertilisers or raw sludge for quick or immediate use in plantations where dehelminthing and sanitation is needed and heavy metal concentrations are in the permissible range.

Input: mixture of raw and surplus sludge of WWTP, mineral fertilisers, ash creating pH ≥ 12.

Process: 1. Making a mixture of ash and sludge and holding it for ≥ 4 days

2. Disintegrating the mixture of sludge, ash and mineral fertiliser

3. Neutralising the mixture via biogas bubbling gained from another process.

4. Bringing the mixture as suspension fertiliser into the soil not later than 3 days.

Output: Refined biogas where methane concentration may be over 90% and dehelminthed and sanitised suspension fertiliser for instant use.

Conclusion

1. The yield of methane production from anaerobic excess sludge 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 utilisation is environmentally desirable. Adding waste glycerol 2–5% by weight, the methane productivity per volume of reactor increased around 250–400%. Adding fish residue 2% by weight, the methane productivity per volume of reactor increased up to 290%.

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

4. A special rotor construction is required and a simultaneous disintegration of sludge and mineral nutrients is needed for complete dehelminthing of excess sludge.

5. By combining waste sludge, ash and mineral nutrients and experimenting with different contacting times and mechanical disintegrations with different rotors, environmentally hygienic and safety suspension is attainable.

6. The disintegrated mixture is extremely fine and homogeneous; it also may be considered a bio solid, but containment of mineral nutrients makes it more valuable and it is regarded as a suspension fertiliser**.**

7. If the pH of fertiliser suspension is too high after disintegration, the treatment of the suspension with biogas decreases the pH and the quality of the biogas as an energy source improves.

8. Several technologies can be created to direct excess sludge into the soil as fertiliser. Permissible concentrations of heavy metals must be considered and adequate legislation followed.

9. Aside from industrially produced mineral fertilisers, all other components, such as sludge, ash, glycerol and fishery residues, are wastes that are directed into the soil as fertiliser. The complex processing produces an enhanced quantity of gas energy.

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