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ANAEROBIC TREATMENT OF SLAUGHTERHOUSE RESIDUES IN MUNICIPAL DIGESTERS

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ABSTRACT

The tendency to increase the number of units processed per day at slaughter yards (up to 8000 hogs daily), as well as new regulations (recycling and waste laws) in Germany, necessitate extensive utilisation of the residuals coming from slaughter yard operations. Anaerobic digestion appears to be an ideal use for the wet pasty residuals, that have little structure and a water content greater than 70%. The anaerobic digestion of sludges from municipal treatment plants in digesters, has been recognized as the state of the art process for decades. Due to changes in regulations (demands on nitrogen elimination), many digesters still have excess capacities, that allow the co-treatment of additional residuals (cosubstrate). Since little experience has been gained in co-treatment of slaughter waste in municipal digesters, a pilot plant was operated to simulate the process before planning large scale operation. This paper presents the results of the pilot plant, as well as the first months of the co-treatment of stomach contents and slaughter flotation tailings in a municipal digester.

KEYWORDS

Anaerobic digestion; anaerobic co-treatment; municipal digester; slaughterhouse; slaughterhouse residues; stomach contents; flotation tailings.

RESIDUES FROM SLAUGHTER YARDS

During the slaughtering process, the muscle tissue, the so called slaughter by-products (e.g. liver, bones) and slaughter waste (e.g. hooves) accumulate. The meat and by-products (such as liver, etc.) are fit for human consumption and can be traded freely. The residues, not fit for human consumption, produced in the slaughtering process are divided into two categories: 1) residues that have commercial value and are tradable; such as fats and bones which find use as raw material in feed plants or in the pharmaceutical industry; and 2) non-tradable residues, such as meat unfit for consumption. These and other by-products need to be treated in animal cadaver disposal plants (CDP), if there is no market for them.

Residues produced during the slaughtering process need to be taken into consideration under the recycling and waste laws and need to be utilised other than in CDPs. These residues consist of primary waste: bedding material, faeces, urine, stomach and intestine contents as well as secondary waste from the wastewater treatment (screening from truck washing and stables (green line), flotation sludge). According to the ATV (ATV, 1995), the following residue amounts accumulate: the amount of bedding material, manure, dung and urine resulting from the cleaning trucks and stables, is around 2.2 kg per hog and around 10 kg per cow. The stomach and intestine contents amount to around 3.2 l per hog and around 18 l per cow, the extra stomach contents of cows amount to between 40 and 80 l. The screenings, depicted by the green line, amount to around 0.5 l/slaughtered unit. The flotation tailings amount to around 0.5 l to 4.5 l for hogs and around 4 l to 24 l for cattle. The ingredients of these residues can be seen in ATV (1995).

COMPARISON AND EVALUATION OF POSSIBLE UTILISATION METHODS

The dumping of the slaughter yard waste listed above will no longer be possible in Germany in the future, because according to the given regulation, all waste that can be utilised, must be utilised. They are not suited for thermal utilisation (incineration), due to the high water content, which causes the calorific value to be below the required 11000 kJ/kg. Drying the waste prior to incineration would be too expensive. Direct agricultural application together with other fertilizers is common practice for the waste bedding material, manure, dung and urine and partially for the screenings (green line) and will remain so in the future. Regulations concerning fertilizing must observed.

Composting reduces organic substances under aerobic conditions. Due to the exothermic process taking place, the residues are hygienised. The resultant compost can be utilised as soil fertilizer. The disadvantages of composting are the great demand in area needed for the process, as well as the odours that arise from it. The great oxygen demand of this process only makes it suitable for waste that has a low water content and sufficient fibrous structure. Composting is suited for the bedding material and manure as well as for the solids remaining after dewatering the extra cow stomach contents. After extensive dewatering and/or mixing with more structured fibers (e.g.hedge clippings), all other slaughter waste, except for the flotation tailings, are compostable.

During anaerobic digestion the organic substances are converted into CH_4 and CO_2 (biogas), by various groups of microorganisms. Stabilisation takes place in the process. An extensive hygienisation only takes place if the process takes place under thermophilic conditions. The anaerobically treated substances can either be applied directly as agricultural fertilizer or treated further with an additional composting step. For pasty substances with little fibrous structure and a water content over 70%, anaerobic digestion is the best suited method of utilisation. With regard to slaughter waste, this applies to the flotation tailings and the dewatered form of the stomach and intestine contents.

MATERIAL/METHODS

Three anaerobic pilot plants were operated in parallel at the municipal wastewater treatment plant of the city Rheda-Wiedenbrück, each consisting of a continuously stirred reactor with a liquid volume of 2000 l (plant 3: 1000 l) (filled level 1.3 m). The reactor contents were mixed using a stirrer and circulated by means of an external eccentric screw pump The temperature was maintained at 37°C using a reactor jacket heater. The loading occurred once daily, also using a eccentric screw pump, after substrate to be added was analysed. A dosing apparatus was used to raise the pH for a certain period, using sodium hydroxide solution. The gas volume produced was continually monitored.

The experiments were carried out in two steps. First, stomach contents from a neighboring slaughter yard were added as cosubstrate. Then flotation tailings from the slaughter yard wastewater flotation system were used. The base substrate was the raw sludge of the municipal plant, which was not very homogeneous, consisting of a mixture of primary sludge, excess sludge and precipitaion sludge from the municipal treatment plants of Rheda and Wiedenbrück. The low homogeneity resulted from partially alternating sludge loading of both treatment plants, different operational settings (the raw sludge wasn't always thickened), as well as from the fact that major construction was taking place at the municipal plant while the experiments were in progress. The following table shows the constitution of the substrates and variations that took place during the experiments.

Table 1. Characteristics of the substrates used in pilot plant experiments

		raw sludge			stomach contents			slaughter flotation tailings		
		Average	min	max	average	min	max	average	min	max
PH	[-]	6.9	6.5	7.6	3.7	3.2	4.4	6.9	6.6	7.19
TS	[%]	2.4	0.9	5.4	17.4	9.3	23.2	5.6	4.3	6.8
Ignition loss	[%]	69	54	79	82	65	94.7	68.4	61	75
VSS	[mg/l]	16.183	6.120	31.200	146.450	61.662	223.250	37.454	26.600	49.600
COD_{hom}	[mg/l]	37.863	13.320	67.280	232.020	79.300	378.200	87.025	75.160	101.460
COD_{filt}	[mg/l]	1.740	1.234	2.502	-	-	-	2.088	1.334	3.170
TKN	[mg/l]	1.413	888	2.210	4.105	2.412	7.239	3.870	2.741	5.300
NH_4-N	[mg/l]	112	60	180	-	-	-	75.0	26.0	118.0
P_{tot}	[mg/l]	730	311	1.675	783	280	1575	658	469	1.060
Organic acids										
Acetic acid	[mg/l]	658.6	194.6	1.453	-	-	-	186.9	78.8	250.1
Propionic Acid	[mg/l]	265.1	109.8	524.8	-	-	-	84.9	44.4	128.4
Sum	[mg/l]	1.220	379.4	2.689	3.736	1.212	6.360	329.7	137.3	479.7

The stomach contents used had higher concentrations of TS and COD than those that are considered average according to (ATV, 1995) (the average TS content was 17.4%, compared to 10%), while the nitrogen concentration was only half as high. The sulphate concentration was around 600 mg/l, while the sulphide concentration was under 1 mg/l. The deviation of all parameters was ±100% of the average. The high concentration of organic acids, as well as the low pH value of 3-4 indicate that the freshly delivered stomach contents were already partially acidified.

In order to facilitate easy handling of the flotation tailings, the scraper speed was set to an average tailings TS concentration of 5.6%. This is comparatively low. Also notable is the relative low ignition loss of 68%. The flotation tailings remained relatively homogeneous through the phase of experimentation, the deviation was about ±30% of the average. A pH neutralisation had already taken place in the flotation process step.

The basic settings of the experimental program are shown in Table 2. Reactor 1 was loaded with 100% of the cosubstrate for the entire duration of the experiment (therefore this represented sole treatment, rather than co-treatment), reactor 2 received 25% (and 30%) of the substrate volume as cosubstrate and reactor 3 had 12.5% (and 0%) of the loading volume as cosubstrate. While the loading percentages of the substrates remained constant during the course of the experiment, the load was increased during the different phases and the hydraulic retention time shortened accordingly.

Table 2. Settings of the pilot plant experiments

stomach contents co-treatment										
		Reaktor I		Reaktor II			Reaktor III			
phase		1	2	1	2	3	1	2	3	4
time frame		9.6-5.9.	6.9-3.10.	9.6-7.7.	8.7-7.9.	8.9-3.10.	9.6-7.7.	8.7-3.8.	4.8-7.9.	8.9-3.10.
temperature	[°C]	37	37	37	37	37	37	37	37	37
pH	[-]	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
retention time	[d]	44	25	20	25	17	20	25	25	17
influent	[l/m³]	22.5	40	50	40	60	50	40	40	60
cosubstrate	[% of Vol.]	100	100	30	25	25	0	0	12.5	12.5
volumetric loading	[kg oTS/m³*d]	3.2	5.8	3.1	2.0	2.9	1.3	1.2	1.3	2.0
cosubstrate	[% of oTS]	100	100	72	67	67	0	0	46	46

flotation tailings co-treatment										
		Reaktor I			Reaktor II			Reaktor III		
phase		1	2	3	1	2	3	1	2	3
time frame		14.10-4.11.	5.11-17.11.	18.11-15.12.	14.10-4.11.	5.11-17.11.	18.11-15.12.	14.10-4.11.	5.11-17.11.	18.11-15.12.
temperature	[°C]	37	37	37	37	37	37	37	37	37
pH	[-]	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
retention time	[d]	44	30	25	25	20	15	25	20	15
influent	[l/m³]	22.5	33.5	40	40	50	66	40	50	66
cosubstrate	[% of Vol.]	100	100	100	25	25	25	12.5	12.5	12.5
volumetric loading	[kg oTS/m³*d]	0.53	0.89	1.54	0.68	0.99	1.67	0.63	0.94	1.46
cosubstrate	[% of oTS]	100	100	100	43	43	43	25	25	25

RESULTS OF CO-TREATMENT OF HOG STOMACH CONTENTS

Table 3 represents the results of the different phases with averaged values.

The anaerobic fermentation of 100% stomach contents was possible with a retention time of 44 days and the addition of sodium hydroxide. The high organic acid concentration, as well as the low specific gas production with an average methane content of 40%, indicate that the acidification in the reactor took place, but the methanogenesis was incomplete. By reducing the retention time to 25 days, the methanogenesis completely stopped. Based on these results, sole anaerobic treatment of stomach contents can not be recommended.

In reactor 2 the 25% volume stomach content constitutes about 67% of the loading, so that the cosubstrate was a significant portion of the load. Figure 1 shows, that reactor 2 didn't maintain stable oTS concentrations, when the retention time was set at 20 days, but when it was increased to 25 days, it stabilized at 20 g oTS/l. The course of the most important parameters during the three experimental phases (see Table 3) support that reactor 2's performance improved during the 4 months of operation and that the best results were achieved towards the end of the last experimental phase, even with an increased loading. The oTS degradation rate increased from 50% to 68%, while the ignition loss was reduced from 66% to 61 %, the concentration of organic acids dropped from over 5000 mg/l to 1660 mg/l and the specific gas production, as well as the methane content in the biogas was increased significantly.

Table 3. Results of the pilot plant experiments (averages of the experiment phases)

stomach contents co-treatment

		Reaktor I		Reaktor II			Reaktor III			
phase		1	2	1	2	3	1	2	3	4
time frame		9.6-5.9.	6.9-3.10.	9.6-7.7.	8.7-7.9.	8.9-3.10.	9.6-7.7.	8.7-3.8.	4.8-7.9.	8.9-3.10.
eta oTS	[%]	67	67	55	45	68	46	47	44	60
ignition loss in	[%]									
ignition loss ef	[%]	60	58	66	61	61	54	56	61	59
org. acids ef	[mg/l]	10.480	-	5.314	4.619	-	1.863	1.544	1.730	-
gas amount	[l/kg oTS]	160	53	255	350	436	488	270	730	297
methane content	[%]	40	17	44	48	52	57	-	55	41
TKN	[mg/l]	2.067	-	1.855	2.265	-	485	552	926	-

flotation tailings co-treatment

		Reaktor I			Reaktor II			Reaktor III		
phase		1	2	3	1	2	3	1	2	3
time frame		14.10-4.11.	5.11-17.11.	18.11-15.12.	14.10-4.11.	5.11-17.11.	18.11-15.12.	14.10-4.11.	5.11-17.11.	18.11-15.12.
eta oTS	[%]	57	62	64	46	52	58	41	45	58
ignition loss in	[%]									
ignition loss ef	[%]	52	55	58	52	55	57	52	55	55
org. acids	[mg/l]		220	bis 6.678		240	300		210	90
gas amount	[l/kg oTS]	566	501	569	657	579	625	504	458	488
methan content	[%]	66	66	62	66	66	66	67	67	66
TKN	[mg/l]		1.455	2.514		1.219	1.639		1.230	1.419
NH_4-N	[mg/l]		726	1.810		668	1.011		621	834

The evaluation of the performance of reactor 2 is limited to the last experimental phase, since that is when the operational stability was the greatest and the most important parameters were constant. The parameters: oTS degradation, organic acid concentration, ignition residue and the specific gas production are used to determine the degree of stability. The oTS degradation rate supposedly begins technical digestion, when a degradation of 72% is reached, based on the substrate composition according to Keefer (cited in Roediger, 1990) (68% were present). If one considers the maximum degradation potential of stomach contents (Tritt, 1993), which is given as 72-90% and weights the raw sludge fraction also, the results end up in the lower portion of the maximum degradation range. The concentration of organic acids, around 1660 mg/l, is higher than values found in many publications, which claim this should be around 1000 mg/l (Harnack, 1992). This also should be evaluated with respect to the substrate. Due to the substrate dependency and the lack of reference values, it is not possible to determine whether the technical digestion limit is reached with a ignition loss of 61%. The specific gas production of the stomach contents was 440 l/kg oTS_{in}. Considering a methane content of 52%, the resultant specific methane yield of 229 l/kg oTS_{in} , is close to the value found in literature (Tritt, 1993) which cites a yield of 250 l/kg oTS_{in}, and also is an indication for stabilised sludge.

Reactor 3 was initially used as a reference reactor, operated without the cosubstrate of stomach contents. After approximately half of the experimental phase, a cosubstrate loading of 12.5 vol % (= 46% load) was added. In contrast to reactor 2, no sodium hydroxide solution was added for pH control as most municipal digesters aren't equipped with dosage apparatus either. However, the remaining experimental phase was not sufficient for an appropriate adaptation to take place and acidification took over the reactor due to the higher loading.

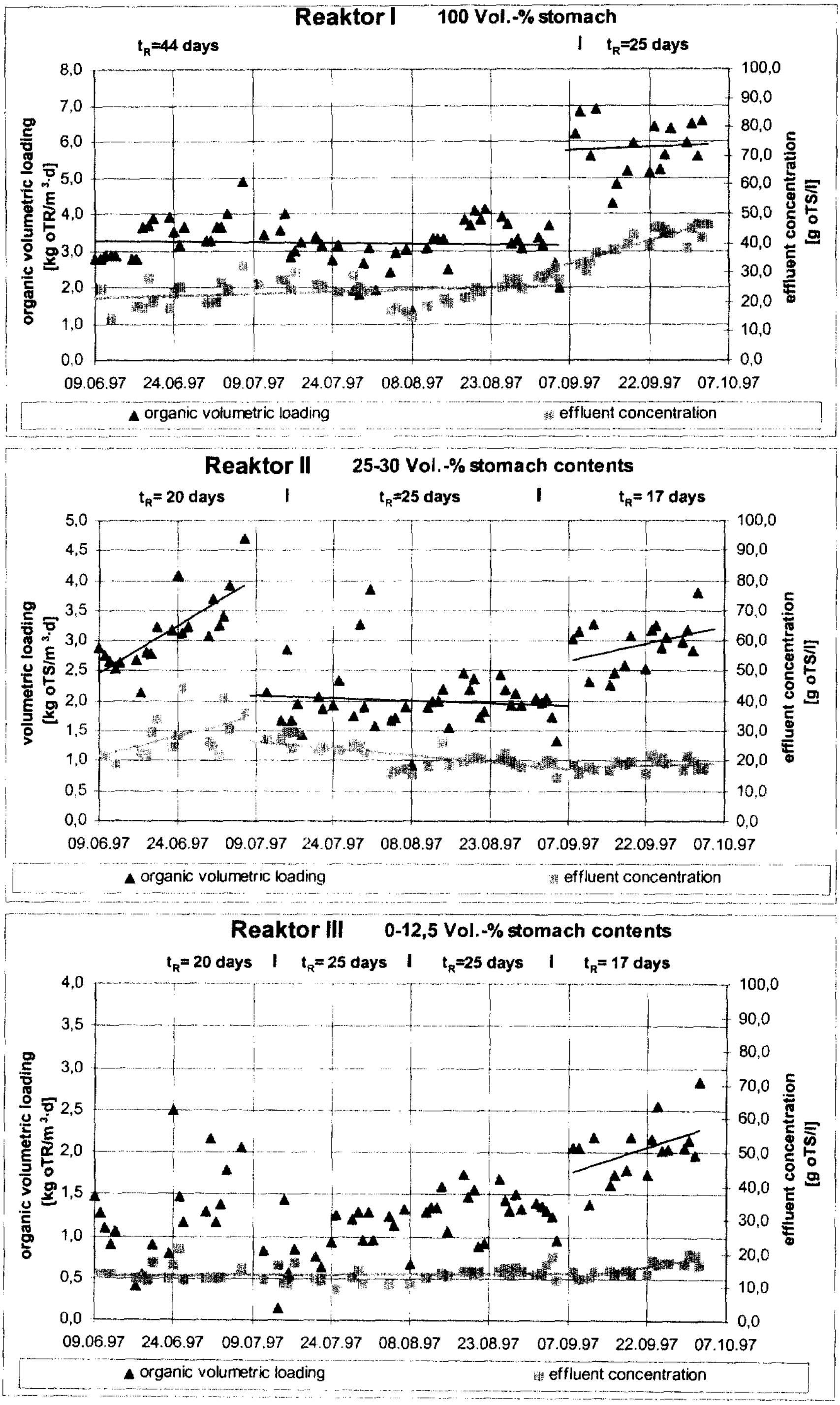

Figure 1. Organic volumetric loading and organic effluent concentration with hog stomach contents co-treatment.

In summary, it can be stated, that with the co-treatment of stomach contents, after a longer adaption phase with a 25 volume % (= 67% load) of stomach contents, a retention time of 17 days and an organic volumetric loading of 2.9 kg oTS/(m^3/d) a stable operation and nearly complete stabilisation was obtained. A substantially lower loading fraction should be taken for the large scale application to ensure the necessary stabilisation along with stable operation.

The co-treatment of stomach contents requires more operational effort and expense. The high straw and chaff content (amounts vary from 5-30 vol%) were reduced in size by means of a macerator. Due to the high cellulose content, the masticated straw was not degraded anaerobically, so that around 12% of the stomach content fraction remained as a floating layer. A screening of the straw and chaff prior to treatment would take great effort and be only partially successful, due to the consistency of the medium. In large scale applications, a floating layer removal system should be recommended. The sand and grit accumulation was relatively small. Other obstructing contents, such as pieces of plastic and wrappers were only encountered once a week. The sodium hydroxide solution consumption (40% NaOH) averaged 5 ml/l stomach contents; the addition of sodium hydroxide isn't necessary when smaller stomach contents fractions are added. The additional nitrogen and phosphorus backloading from the sludge dewatering can be estimated based on the ratio of cosubstrate addition. The increased load will cause additional backloading, but since the stomach contents have a substantially better C/N- and C/P-ratio than municipal sludge, the increased loading will be minimal.

RESULTS OF SLAUGHTER FLOTATION TAILINGS CO-TREATMENT

The most important results of the experimental phases are shown as mean values in Table 3.

The 25 volume % flotation tailing fraction in reactor 2 represented around 43% of the loading, in reactor 3, 12.5 volume % flotation tailing fraction made up around 25% of the loading. Figure 2 shows that the volumetric loading was increased during the experimental phases. The increase results from the shortening of the hydraulic retention time and from the undesirable concentration increase during the experimental phase.

Reactor 2 and reactor 3 exhibited stable operation during the entire course of experiments and gave good results. Also noteworthy is the fact that both reactors not only produced constant results while increasing load (reduction of retention time from 25 to 15 days), but that reactor 2 and reactor 3 demonstrated similar results. The organic acid concentration in both reactors always remained 300 mg/l and therefore lower than the value considered to be the stability limit listed in Harnack (1992). The methane content of the biogas in both reactors was 66-67% at all times. The effluent oTS concentrations represented in Figure 2 show no major differences between reactor 2 and 3, the loading increase only has a minimal impact on the effluent quality. Based on the loading increase, the oTS degradation rate increased from 46% (41%) to 58% at the end of the experiments. Considering the substrate characteristics, the technical digestion limit is reached with a 62% degradation rate according to Keefer (cited in Roediger, 1990). The increase in the effluent ignition loss from 52 % to 55% (57%) resulted from a proportional increase of the ignition loss of the influent.

In summary, based on the results from reactor 2 and 3, up to 25 % volume flotation tailings can be co-treated (loading = 43%), with a retention time of 15 day (organic volumetric load = 1.5 kg oTS/(m^3/d)), while maintaining a stable operation and stabilisation of the sludge is also accomplished.The specific gas production of the flotation tailings is between 600 l/kg oTS_{in} (reactor 3) and 800 l/kg oTS_{in} (reactor 2) and lies in the lower to middle range of the values found in literature (Dekena, 1995; KTBL, 1997; Tritt, 1992).

It was not possible to determine whether the sole anaerobic fermentation of flotation tailings can be operated with stability, from the results obtained operating reactor 1. Figure 2, as well as the data in Table 3 indicates that during the first two experimental phases stable operating conditions with good results were reached. The specific gas production was lower than those of reactors 2 and 3, however. During phase 3, acidification increased in the reactor. Since this took place at the end of the experimental phases, it was not possible to find an explanation for this phenomenon or to take measures to counteract this process.

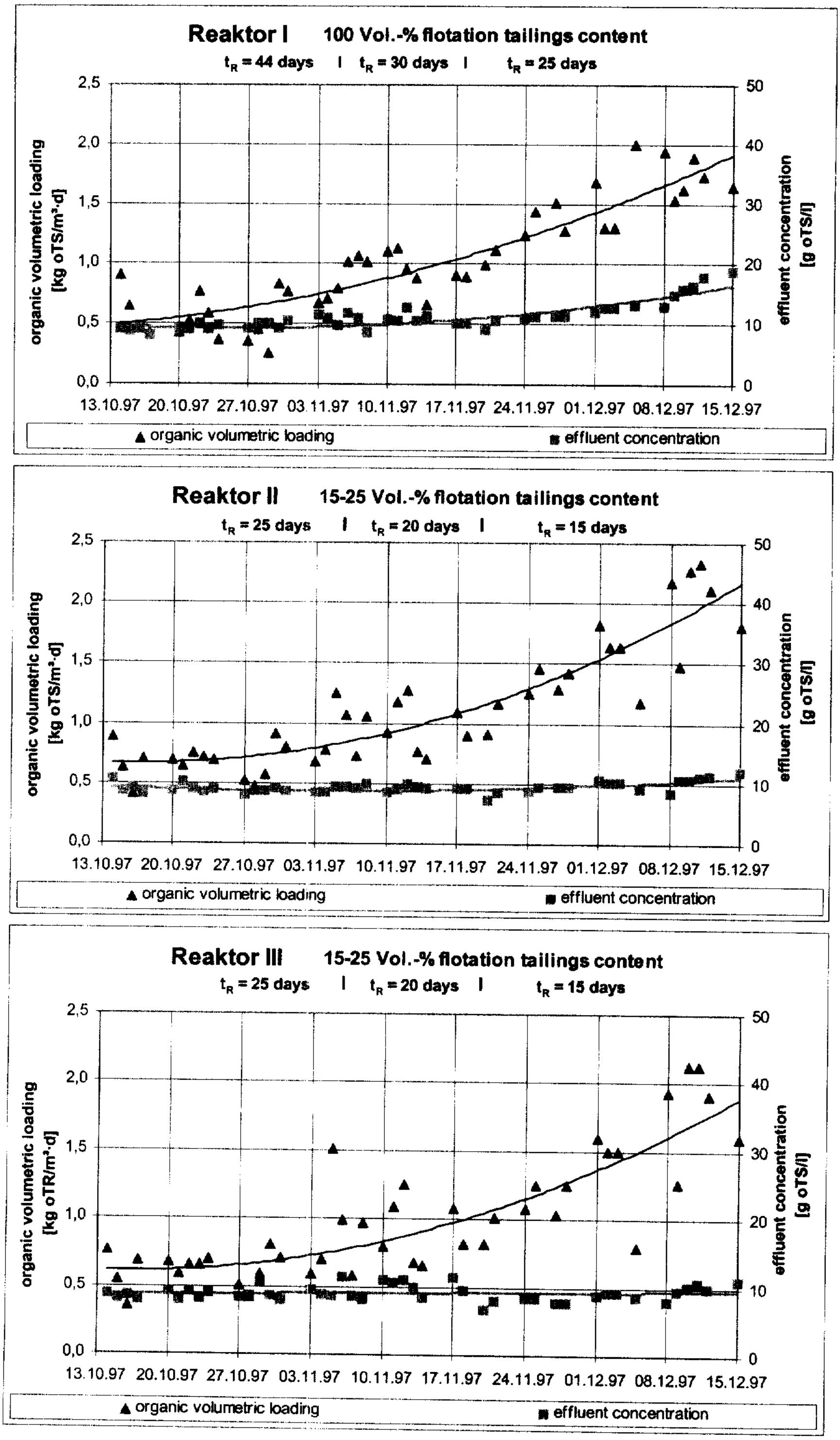

Figure 2. Organic volumetric loading and organic effluent concentrations during flotation tailings co-treatment.

From an operational perspective, it should be mentioned that no pretreatment of the flotation tailings was necessary, but that a high recirculation rate was used. Problems with deposits and floating layers did not arise. The addition of sodium hydroxide was not necessary at any time, either. With regards to the nitrogen and phosphorus back loading, it should be pointed out, that the flotation tailings have approximately the same C/N ratio as the raw sludge, while the C/P ratio is only about half of that found in the raw sludge.

RESULTS OF FULL SCALE CO-TREATMENT

The digester of the municipal treatment plant of the city Rheda-Wiedenbrück (volume: 5000 m^3) was loaded with flotation tailings and stomach contents from a newly constructed slaughter yard from November 1997. The flotation tailings (averaging 37 m^3/d, with a mean TS content of 5.6%) were loaded directly from the flotation plant, located on the municipal treament plant grounds, into the recirculation pipe of the digester through a pressure pipe and mixing injector. The stomach contents (averaging around 50 m^3/week, with a mean TS content of 17%) were delivered to the municipal plant by tanker trucks (equipped with an internal circulation shredding pump) 2-3 times a week and passed through a grit chamber, macerator and mixing injector into the recirculation pipe of the digester. The specific characteristics of the raw sludge and cosubstrate can be found in Table 1. The addition of the cosubstrate increased the influent amount by about 18%, reducing the calculated hydraulic retention time in the digester from ca. 21 to ca. 18 days. The oTS volumetric loading was increased by about 61%, from 0.78 Kg oTS/(m^3/d) to 1.26 Kg oTS/(m^3/d).

The increased volumetric loading posed no problems for the digester, the reduced retention time can be extended, if needed, by further thickening of the raw sludge (raw sludge is often added without being thickened, the average TS content is 2.37%). Since the gas portion of the digester was in need of repair, the new gas lines were dimensioned for the increased gas amounts. Figure 3 shows that the cosubstrate addition produced a gas production increase of 1136 m^3/d, a about 60% increase. The specific gas production of the combined cosubstrates, about 470 l /kg oTS_{in}, is somewhat higher than that of the raw sludge. Operational problems, such as clogging or deposits have not arisen. Due to the straw and chaff fraction of the stomach contents, an increase of thickness in the swimming layer was observed. The anticipated worsening of the dewatering characteristics of the digested sludge did not take place. The ammonium concentrations in centrifuge effluent increased to about 900 mg/l.

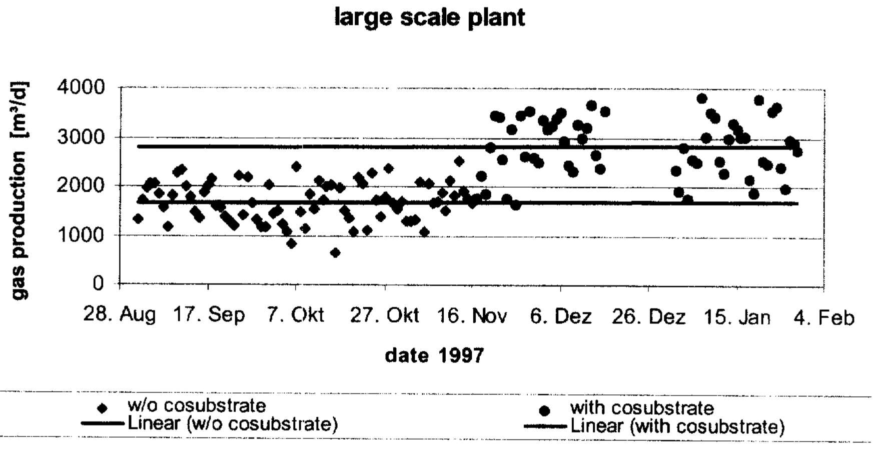

Figure 3. Digester gas production of the treatment plant in Rheda before and after the addition stomach contents and flotation tailings.

APPROACHES FOR OPERATORS OF EXISTING DIGESTERS

Operators considering the treatment of cosubstrates, should examine the following 5 points.

1. Precise calculation of availible capacities in the present plant (digester, gas system, dewatering system, disposal method, personel capacities) as well as exact knowledge of the chacteristics of the present digested sludge with respect to the sensitivity of certain ingrediants.
2. Choice of cosubstrates with consideration of amount, consistency and the significant ingrediants.
3. Evaluation of possible advantages and disadvantages:

Advantages:
- Revenues for residue disposal
- increased gas production
- better utilisation of the availible capacities
- better quality of the end product (reduction of heavy metal concentration, improvement of dewatering characteristics, increased degree of stability)

Disadvantages:
- possible additional construction requirements (unloading station, coarse debris removal, macerator)
- increased operational expense and effort operational stability (deposits, floating layer development)
- increased nitrogen, phosphorus, rest COD back loading
- increased amounts of end product.

4. Where there are no experiences from other co-treatment operators to refer to, there is a substantial cosubstrate amount to be treated or there is uncertainty about the points mentioned above, pilot scale experiments should be run prior to implementation.
5. If the decision for co-treatment is made after proper evaluation and experimentation, approval for the added cosubstrate must be applied for and contracts must be draw up with the cosubstrate provider and digested sludge remover (securing disposal).

CONCLUSIONS

The recycling and waste law in Germany dictates the utilisation of certain residues from slaughter yards. Anaerobic digestion seems to be the best utilisation of the stomach contents and flotation tailings, which are pasty, have little fibrous structure and a high water content. This publication presents the results of the pilot plant simulation, as well as the first months of the co-treatment of stomach contents and slaughter flotation tailings in a municipal digester.

After a longer adaption phase, the co-treatment of stomach contents from hogs was successfully carried out with 25 volume% (= 67% loading) cosubstrate, a retention time of 17 days and an organic volumetric loading of 2.9 kg oTS/(m^3/d). A stable operation and extensive stabilisation of the sludge was obtained. A smaller load fraction should be chosen for large scale application. The specific gas production of the stomach contents was 440 l/kg oTS_{in}. The sole digestion of the stomach contents was not possible. The co-treatment of stomach contents in municipal digesters is a viable option and an acceptable means of utilisation, but demands higher operational expense and effort (coarse material removal, macerator, sodium hydroxide dosage with larger cosubstrate loads, increased floating layer development). The regulations regarding the disposal parameters and hygienisation must be considered on individual basis.

A 25 volume % co-treatment of slaughter flotation tailings in municipal digesters (loading = 43%) with a retention time of 15 days (organic volumetric loading = 1.5 kg oTS/(m^3/d) was operated with stable conditions and good results. The specific gas production of the flotation tailings was 600-800 l/kg oTR_{in}. The flotation tailings co-treatment requires no pretreatment or neutralisation. No grit or other coarse materials were found in the tailings. Problems with deposits and floating layers did not arise. The co-treatment of slaughter flotation tailings in municipal digesters is possible with little additional operational effort and goods results were obtained. The increased gas yield makes the process economically feasible.

At this point it should be mentioned that the regulations regarding the disposal and hygienisation are not regionally uniform. In solid slaughterhouse residues there is still concern regarding the potential presence of prions (BSE, mad-cow disease) with makes further studies about their inactivation during biological or thermal treatment process necessary.

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