Thermal hydrolysis (TDH) as a pretreatment method for the digestion of organic waste

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Abstract The recycling concept under consideration is based on the process of Thermal Hydrolysis (TDH) followed by an anaerobic digestion. By increasing pressure and temperature the organic part of the waste is split up in a first step into short-chain fragments that are biologically well suited for microorganisms. The following fermentation runs much faster and more complete than in conventional digestion processes and the biogas yield is increased. Left is just a small amount of a solid residue that can be easily dewatered and utilized as surrogate fuel for incineration or as compost additive. The thermal hydrolysis process allows a complete energy recovery from organic waste. During the total procedure more energy sources are produced than are needed for running the plant. The procedure is especially suited for wet organic waste and biosolids that are difficult to compost, such as food scraps, biological waste from compact residential areas and sewage sludge. As a complete disinfection is granted due to the process temperatures the procedure is also suited for carcasses.

Keywords Anaerobic digestion; biogas; biological waste; biosolids; hydrolysis; organic waste; recycling; thermal hydrolysis

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Introduction

In Germany, food scraps from canteens and restaurants need to be disposed of in accordance with the law on the disposal of carcasses. They may only be used as animal feed after a prior treatment at a plant for the disposal of carcasses. This is not only costly, but the admixture of this waste also reduces the quality of the animal meal. Therefore alternative processes are needed. Anaerobic digestion, which aims at the production of biogas, is of increasing interest for recycling food scraps. Most of the time this waste is processed in cofermentation together with material from the biowaste can. Treatment costs, however, are high, because the wastes have to be previously processed in hygienic conditions for epidemic hygienic reasons (Bioabfallverordnung, Germany, 1998).

In the following a new recycling concept will be presented that does not only offer an accelerated digestion with an increased biogas yield, but also integrates the advantage of a guaranteed processing in hygienic conditions. The concept combines a temperature and pressure catalyzed hydrolysis called Thermal Hydrolysis, TDH, and a subsequent anaerobic digestion of the hydrolysate.

Thermal hydrolysis with subsequent anaerobic digestion

The anaerobic biological decomposition is generally considered to be a fourstep process: hydrolysis, fermentation, acetogenesis and methanogenesis. In the first step, the hydrolysis, solid reactants have to be rendered soluble. Only in a water-soluble state can they penetrate the cells of the microorganisms to become degraded further (Kunst, 1993). From a chemical point of view hydrolysis means the breakdown of long-chain biomolecules by the reaction with water. The resulting short-chain hydrolysis products, which are water-soluble, can easily be converted into biogas by anaerobic microrganisms. Biologically, the hydrolysis works through the influence of enzymes (Verstraete, 1981; Stadlbauer, 1984; Schraewer, 1988; Fox, 1994). For many substrates, especially for solids, hydrolysis often is the slowest and most speed-limiting step in anaerobic biodegradation processes.

Up to now various authors have performed experiments on physico–chemical treatments in order to enhance the hydrolysis of heavily biodegradable substances. Pretreatments at high temperatures and pressures under acid conditions, for example, have been examined for the hydrolysis of celluloses and hemicelluloses as a prior step to the microbiological production of ethanol (Lorenz, 1972; Sakaki, 1996; Torget, 1996). The thermo-chemical splitting of fats to gain fatty acids is performed on a technical scale (Brockmann, 1985). For the treatment of sewage sludges it was found that a high temperature treatment not only enhanced the hydrolysis grade but also improved the dewatering properties – up to 50 % dry matter – of the remaining solids by destroying the bacteria cell walls (Jung, 1996).

In this context, the TDH – process presented in this paper offers the possibility to anticipate the relatively slow enzymic hydrolysis by a specific treatment at increased pressure and temperature. The hydrolytic breakdown of the biopolymers of the bio-wastes is achieved, unlike in the enzymic process, through the influence of pressure and temperature. The temperature activated hydrolysis is not only fast (treatment time <60 min) but also has quantitative advantages. Altogether up to 70% of the dry matter of the wastes were found to be hydrolytically converted and dissolved during the aqueous phase (Bischof, 1997; Schieder, 1998).

The complete process, sketched in Figure 1, is described as follows: The organic material to be recycled is first transferred from a delivery bunker to a masher where it is mashed up with recirculating water to get the necessary dry matter content of approximately 13%. At the same time interfering material is isolated in a sink-swim-procedure. In a subsequent treatment step the material is crushed into the necessary grain sizes and put in the intermediate storage tank. From this tank the newly developed hydrolysis jet reactor is filled. During the thermal hydrolysis the liquid phase is enriched with organic material. Besides, small amounts of gaseous fission products arise, especially CO_2 and CO (hydrolysis gas). A following separation step divides the raw material into several fractions. During the cooling and expansion phase the occurring hydrolysis gas is first collected. The solid residual non

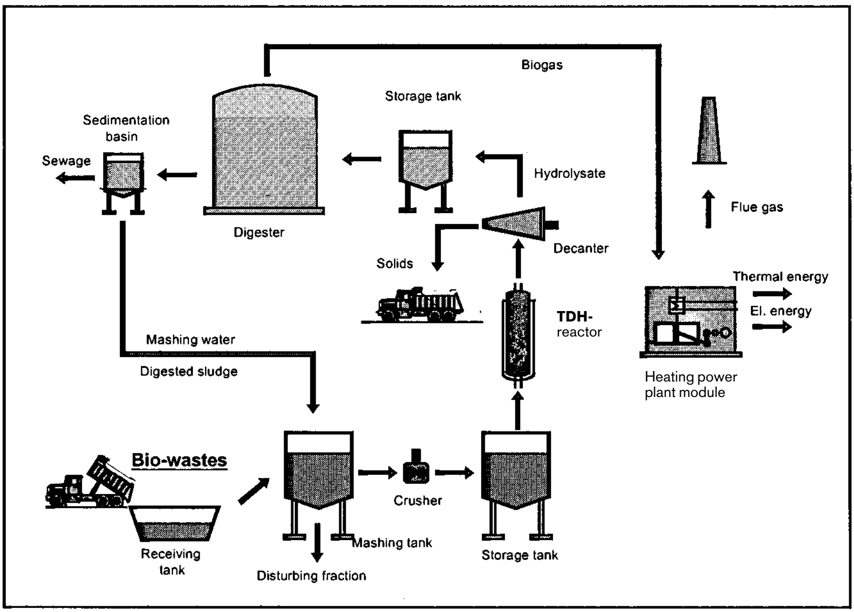

Figure 1 Treatment of organic wastes by Thermal Hydrolysis (TDH) and subsequent biogas production by anarobic digestion

hydrolyzable material can either be separated and dewatered right after the stripper – as is shown in Figure 1 – or, if it is sufficiently biodegradable, can be added together with the liquid hydrolysate phase as a suspension to the anaerobic digestion process. The separate fractions are further treated with the aim of reaching the best possible energy recovery.

From the hydrolysate biogas is produced in a fixed bed digester. Its energy recovery takes place in a block combined heat and power station with a simultaneous combustion of the hydrolysis gas. A solid/liquid separation step allows us to use the digestion water again to mash the newly arriving material. The residual solid material is dewatered and can either be used as a compost additive or, since it shows a high calorific value, be thermally utilized as surrogate fuel.

The TDH – process has so far been successfully explored in laboratory scale concerning the recycling of sewage sludge (Hertle, 1994; Tippmer, 1994; Chwistek, 1997; Radke, 1998) and waste from the biowaste can (ATZ-EVUS, 1997). Concerning a large-scale application there are experiences for the treatment of sewage sludges. Several producers, for example, run plants for the hydrolysis of sewage sludges in Tampere, Finland (Drescher, 1998), and at the sewage treatment plant in Helsingborg, Sweden (Anonymous, 1996). To our knowledge, the procedure for the treatment of biological wastes has not been tried in a large-scale application so far.

Experiences in a semitechnical plant

Currently ATZ-EVUS in Sulzbach-Rosenberg runs a continously working semitechnical TDH - plant for recycling food scraps and canteen waste with a capacity of 1800 t raw material per year.

The essential part of the plant is a 0.15 m^3 jet reactor (Figure 2), which is fed via a high-pressure pump with previously mashed and wet ground material. The TDH – process takes place in this circulation reactor at increased pressure and temperature. After passing through the reactor the product mixture is expanded to atmospheric pressure. In doing so the occurring hydrolysis gas is separated.

Since heat recovery is of advantage for a cost-effective operation, a special heat exchange system was developed, which avoids an impairment of the heat exchangers as was observed at hydrolysis plants of some other operators (Drescher, 1998). With this system 75% of the supplied thermal energy in the temperature range of <220ºC can be recoverd. At the semitechnical plant the residual demand of thermal energy is covered by thermal oil heating. On a technical scale it can be generated from the hot exhaust gases of the block combined heat and power station.

The hydrolysate next reaches the methane tank, which is run as an aerobic upflow fixed bed loop reactor. This basically corresponds to the process sequence of an anaerobic wastewater purification. The occurring biogas is registered by a gas-meter and analytically evaluated with a GC system.

The process conditions during the TDH – process depend on the sort and composition of the biological material to be recycled. In the case of canteen and gastronomic food wastes processing at reactor temperatures between 160 and 200ºC, pressures up to 40 bar and residence times of up to 60 min was most successful. These conditions guarantee the hygienic requirements of the German law on the disposal of carcasses (133ºC, 3 bar, 20 min). A raw material mash with dry matter of 10–15% is used. Most of its organic substance is a solid. At the chosen process conditions 55–70% of the organic solid material are transferred to the liquid hydrolysate phase and are thus, in a subsequent anaerobic digestion step, immediately available for the microorganisms. Table 1 shows the hydrolysis results and the composition of the hydrolysates gained.

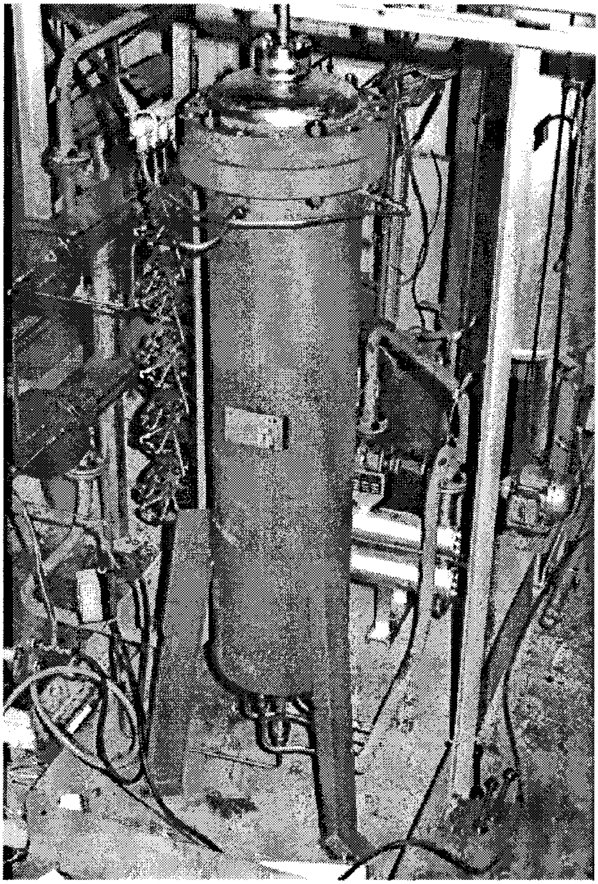

Figure 2 TDH – high pressure jet reactor

Digestion tests in batch operation (laboratory scale) showed that in comparison to the anaerobic digestion of the crushed and mashed raw material, the hydrolysate was not only degraded significantly faster, but the according biogas production also was higher. After only five days the hydrolysate showed constant data for the specific gas production of 500 l per kg added COD resp. 850 l/kg oDS, so that the reactant could be considered almost completely fermented, whereas the raw material reached a gas production of 470 l/kg COD, resp. 780 l/kg oDS only after 20 days (Figure 3).

Table 1 Characteristic parameters of the hydrolysis products of canteen and gastronomic food wastes

Dry matter	[g/l]	100–150
Organic dry matter – oDS	[g/l]	90–130
Fraction of organic dry matter dissolved	[%]	55–70
COD – total	[g/l]	140–170
Fraction of COD – dissolved	[%]	55–70
COD/TOC – proportion		2.5–3.5
Organic acids	[g/l]	1.6–4.4
C/N – proportion		10–14
NH_4–N	[g/l]	0.2–1.3
pH		4.0–4.6

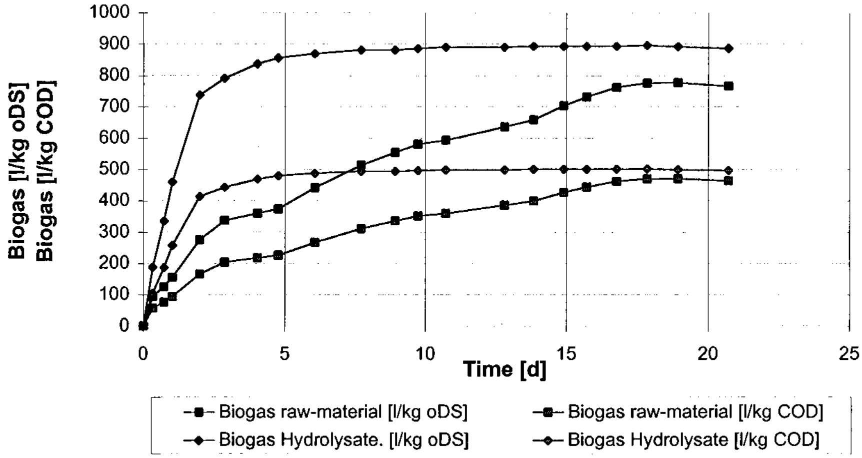

Figure 3 Biogas production of the TDH - hydrolysate compared to the non hydrolyzed raw-material in the laboratory batch scale

Presently several semitechnical methane reactors of 0.5 and 0.2 m^3 are operated. With mesophilic conditions more than 80% of the dissolved COD of the liquid hydrolysate phase can be converted into biogas at organic loading rates of 13–17 kg COD/m^{3}d in only 5 to 6 days. At thermophilic operation the decomposition can even be slightly higher. The solid fractions from the TDH – treatment of canteen and gastronomic wastes are sufficiently biodegradable so that a methanization out of the raw hydrolysate is sufficient to increase the biogas yield. Thus a single stage digestion could be established under mesophile conditions (35–37°C) where approximately 70% of the total material are degraded at a hydraulic retention time of 6–9 days and a COD – loading rate of 15–16 kg/m^{3}d. The digestion results are listed in Table 2. Carrying along the solid did not lead to any negative effects, such as an interlocking of the fixed bed material. On an average there is a daily formation of approximately 7.5 Nm^3 biogas per m^3 reactor volume. The methane content varies between 55 and 70%, depending on the composition of the raw waste.

In principle the procedure of hydrolysate digestion in a fixed bed reactor resembles an anaerobic sewage purification. With a COD load of the hydrolysate of 140–170 g/l total resp. 80–110 g/l dissolved, however, the intake values as well as the loading rates per m^3 and day by far exceed what is common in such facilities – generally less than 50 g/l dissolved COD and loading rates up to 10 kg COD/m^{3}d (Austermann-Haun, 1993) – so that the biology needs to be adapted accordingly. The remaining digested sludge from non-degraded reactant material and anaerobic microorganisms, which is carried along, amounts to approximately 30% of the original raw waste mass related to the dry matter. After separation and dewatering it can be used as a compost additive. Most of the occurring digestion water is used as recycling water to mash the new waste material. At present the excess at the pilot plant is repurified in an aerated fixed bed reactor.

Summary

An overall summary of both procedure steps, TDH and anaerobic digestion, shows a conversion of 60–80% of the fed organic waste material at a total treatment time of less than 10 days; less than an hour in the TDH – reactor and 6–9 days in the fixed bed methane reactor. The reason for the fast biological decomposition is the extensive conversion of the organic matter into water-soluble components during the hydrolysis phase – a total of up to 70% of

Table 2 Results of the digestion of canteen and gastronomic food scrapes pretreated by thermal hydrolysis

Digestion temperature	[°C]	35–37
pH		6.8–7.4
Hydraulic retention time	[d]	6 –9
COD (total) – input	[g/l]	140–170
COD (dissolved) – input	[g/l]	80–110
NH_4–N – input	[g/l]	0.2–1.3
CSB (dissolved) – output	[g/l]	10–18
NH_4–N – output	[g/l]	1.0–1.7
COD – loading rate	[kg/m^{3}d]	15–16
COD (dissolved) – reduction	[%]	80–90
COD (total) – reduction	[%]	65–76
Specific biogas production in relation to the reactor volume	[Nm^3/m^{3}d]	6.1–8.0
Methane content of the biogas	[%]	55–70

the dry feed material. High conversion rates in the TDH – process and a high degradation performance in the anaerobic upflow fixed bed reactor led to above-average biogas yields per reactor volume unit. At the same time the solid residue is minimized. Commonly used procedures for biowaste fermentation operate with residence times of 10–20 days to get similar decomposition rates for canteen waste. Usually, however, canteen waste is not fermented separately but together with material from the biowaste can (Wintzer, 1996). The advantages of the presented process combination for industrial food scraps compared to conventional anaerobic digestion procedures are significant:

- Shortened treatment time and thus
- High mass flow
- Reduction of the methane reactor volumes during the methanization phase and of the total investment costs in spite of additional investment cost for the TDH – equipment
- Reduction of the dry matter of up to 70% and at the same time a
- High biogas recovery
- No separate hygienic steps necessary, since the hydrolysis process already guarantees the necessary hygiene.

The energy demand is covered by internal heat recovery, which results in a positive energy balance and low investment and operation costs.

Beside recycling food scraps and waste from the biowaste can the Thermal Hydrolysis process can also be used for organic residual material from the production sector, e.g. the food processing industry. It is especially suited for waste with a high moisture content. Since the process guarantees excellent hygienic conditions of the treated material, this process combination offers good prospects for recycling special risk material, e.g. where the disposal of carcasses is concerned.

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