RECENT GERMAN TECHNOLOGY IN ANAEROBIC WASTE TREATMENT

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Abstract – Anaerobic treatment of liquid and solid wastes has become a high importance in Germany for pollution control and renewable energy production. Anaerobic digestion processes are applied in agriculture, agro-industry and with increasing success also within the municipal sector. The technology is used on small family-size farms but also on large industrial scale. Within the last three years the application of anaerobic treatment processes has been increased considerably in the different sectors. Only in agriculture the number of installations increased from 140 to 370 plants with an increase of the total reactor volume by a factor of 1.5. The most important applications and recent advances in reactor design and process development will be presented.

Key Words – Anaerobic treatment, Co-digestion, Bio-wastes, Manure

INTRODUCTION

Anaerobic treatment has a long history for waste treatment in Germany, but the process has become growing interest during the last three years due to new legal regulations and recent advances in reactor design and process development. The recycling and waste law which has become effective in October last year, stipulates the recirculation and utilization of wastes for energy or product formation and makes disposal of organic wastes more difficult. The disposal of wastes is allowed only for materials which cannot be utilized due to technological or economical difficulties or whose utilization results in environmental pollution problems. Hence, liquid or solid organic wastes from agriculture, agro-industry and food processing industry but also municipal solid wastes from the separated collection of the organic fraction of household wastes are no longer rubbish which has to be disposed: it's a valuable resource of an economic value which has to be converted into useful products.

Anaerobic waste treatment can avoid waste formation by internal recirculation, it allows a recirculation of nutrients and humus into the agricultural product cycle, it reduces the emissions of climate relevant greenhouse gases, especially of CO₂ and CH₄, and it prevents environmental damages in soil and water by wastewaster treatment or solids stabilization. The anaerobic process conditions results also in a sanitation of the treated wastes which is important for the utilization and recirculation of epidemic risky wastes, e.g. animal manure, slaughterhouse residues or restaurant wastes.

![Biogas plant diagram](image)

Figure 1. Aspects for the application of biogas plants in Germany.
The main fields in which anaerobic processes are utilized in Germany are shown in Figure 1.

The production of renewable energy from wet wastes or special cultivated energy plants is of increasing interest, because Germany will reduce the CO₂-emissions by 25% up to the year 2005. For the biogas production and the co-generation of heat and electricity completely standardized modular units are available. According to the Electricity Supply Act, the generated electricity can be fed into the public grid at a fixed price. Wastewater treatment and solids stabilization are mainly applied for environmental protection whereas agricultural biogas plants are mainly applied for energy production but also to achieve an improvement of the waste properties which should be recycled on fields.

MATERIAL AND METHODS

SUBSTRATES AND ENERGY POTENTIAL

The most important organic residues which should be treated by anaerobic digestion are formed in the agricultural and municipal sector. In agriculture about 190 Million tons of liquid manure with a mean total solids content of 7.5% and approx. 70 Million tons of solid manure with a mean total solids content of 25% are formed per year [1]. Within the municipal sector about 60 Million tons of sewage sludge with about 7.5% dry matter, 8 Million tons of biowastes from household and 4 Million tons of biowastes from trade and business are formed per year [2]. Furthermore, several Million m³ of highly loaded wastewater is formed in agro- and food industry. Figure 2 shows the distribution of the different organic wastes on wet- and dry-mass basis.

The theoretical amount of biogas which can be formed from the total amount of organic wastes is about 7.1 Billion m³ biogas per year which is equivalent to an energy amount of about 150 Peta Joules per year (PJ/a).

Approximately 7% of the German natural gas consumption could be substituted by this biogas potential. About 50% of the biogas potential comes from liquid manure. Hence, anaerobic treatment technologies play an important role in agriculture not only for manure treatment alone but also for codigestion of manure and non-agricultural wastes.

WASTEWATER TREATMENT

In Germany more than 100 anaerobic digesters with reactor volumes between 1000 and 3000 m³ are used in agro- and food-processing industry for wastewater treatment. About 34% of all installed plants are running in the sugar industry, 23% in the pulp and paper industry, 11% in alcohol distilleries, 8% in rendering plants and 5% in the potato processing industry. Anaerobic wastewater treatment processes are also applied in breweries, starch processing, yeast factories and canneries. Dependent on the wastewater type different reactor configurations and mixing devices are applied (Figure 3).

Reactors with biomass accumulation dominate. About 50% of the running systems are working as the sludge contact process with recirculation of biomass which is separated in an external settler. Relatively simple digesters with mechanical mixing or gas injection are used for this process type. Fixed bed reactors (22%) and upflow anaerobic sludge blanket reactors, UASB-reactors (19%) are applied only for wastewater of low suspended solids content. Only one full-scale fluidized bed reactor is installed in Germany for the treatment of
RESULTS AND DISCUSSION

MANURE TREATMENT

The tremendous growth in livestock farming has resulted in serious environmental problems such as pollution of surface and ground water by nutrients, soil pollution and emission of pollutants to the air and atmosphere which promotes the greenhouse effect and the formation of acid rain. To tackle these environmental problems, integrated processing technologies were developed recently in order to separate the manure in a purified liquid phase and valuable products, e.g. fertilizers and soil conditioners. In all full-scale plants for manure treatment anaerobic digestion is always an important process step for the reduction of the organic load, for the destruction of malodorous compounds, the conversion of organic nitrogen to ammonia and the formation of biogas [4].

Two typical process routes for partial purification (plant Göritz) and total purification (plant Bakum) of manure are shown here. The manure treatment plant in Göritz is operated with a two-step anaerobic digestion system with mesophilic conditions in the first stage and thermophilic conditions in the second stage (Figure 5).

About 21 m$^3$ biogas with 63% CH$_4$ is formed per m$^3$ manure which is transformed into electricity and heat in a block-type thermal power station. About 2/3 of the produced electricity (25 kW/m$^3$ gas) is fed into the public grid and 1/3 is necessary for process maintenance. The heat is completely used within the

![Figure 5. Manure treatment plant Göritz.](image-url)
process. The suspended solids are separated and ammonia nitrogen is stripped out by steam in order to achieve an aqueous fertilizer of ammonia hydrogencarbonate and a partially treated manure (turbid water) which contains only 35% of the initial total nitrogen and about 45% of the initial phosphorus. The partially treated manure is free of malodorous substances and completely disinfected due to the thermophilic operation of the second digester stage.

For the anaerobic treatment special tower reactors with integrated sieve plates and hydraulic mixing devices are used (Figure 6).

The reactor design and the internal installations allow a "plug flow" behaviour of the liquid phase and a controlled mixing by liquid recirculation at distinct time intervals.

The plant Bakum is designed for a total manure treatment and produces a purified wastewater of high quality (COD < 100 mg/l, NH₃-N < 10 mg/l, PO₄-P < 2 mg/l) which can be reused on the farm or discharged to a river (Figure 7).

The first process step is the anaerobic digestion of the raw manure in order to reduce the COD content and to improve the flow behaviour of liquid manure which is necessary for the subsequent evaporatorvation of the liquid phase in a tube bundle evaporator. Anaerobic treatment is also necessary in order to achieve a high efficient solids separation by centrifugation, because the evaporator can be operated only with liquids of low solids content. The produced biogas covers the total heat demand and supplies approximately 45% of the electricity demand of the whole plant.

**CO-DIGESTION**

Digestion of liquid manure together with organic wastes from industry, trade and household has become high importance in Germany for waste recirculation and energy generation. Most of the organic wastes from these sources contain high amounts of water, so that composting processes cannot be applied without addition of additives. Co-digestion is the best way for the utilization and recirculation of these wastes because an inhibition of the degradation process due to an unbalanced waste composition or a deficiency in trace elements can be prevented by addition of manure.

Co-digestion results in stable process conditions and higher gas yields as the digestion of the mono-charges. It shows also several advantages regarding waste management and economy, because anaerobic treatment and land application of the treated residues can be done as a service by the farmers [5]. Some typical co-substrates and their origin are shown in Figure 8.

Residues from agro- and food- industry usually are free of impurities and epidemic germs and can be degraded anaerobically without any pre-treatment. A separation of impurities and a disinfection is necessary for organic wastes from slaughterhouses, restaurants, grease removers and households. The pasteurization should be operated at 70°C for 1 h but is not necessary, if the process is operated at thermophilic (1)
Figure 8. Typical substrates for co-digestion.

Figure 9. Biogas potential of different waste sources.

$55^\circ C$) temperature conditions with a real residence time of at least 24 h.

The addition of co-substrates results in a strong increase of the specific biogas productivity (Figure 9).

The maximum biogas yield per ton of cow or pig manure is normally less than 25-36 m$^3$/t whereas co-substrates usually result in a twofold or fourfold gas yield. Fat containing wastes can increase the gas productivity considerably because pure fat wastes result in gas yields of about 800 m$^3$/t, which is more than the 20 fold value of pig manure.

Within the last two years eight large-scale co-digestion plants with reactor volumes between 800 and 3,500 m$^3$ were put into operation. The largest plant which has started-up last year has a treatment capacity of 126,000 tons per year (t/a). For co-digestion relatively simple agricultural biogas plants are applied (Figure 10).

Most of the digesters are operated with a continuous throughflow at mesophilic or thermophilic temperature conditions. The typical hydraulic retention times are between 15 and 25 days. Possible variants of the completely mixed continuous one-stage system are reactors with two-stage operation or horizontal plug-flow systems. Storage tank reactors are operated only on family-size farms at usual temperatures lower than $25^\circ C$ with residence times above 3 month. All reactors have to be mixed carefully in order to prevent scum formation or process instabilities due to local acid accumulations.

**BIOWASTE TREATMENT**

Organic wastes from the separate collection of household and trade wastes are stabilized mainly by composting, but especially for the wet and structureless fraction anaerobic treatment processes becomes more and more popular. One- and two-step digestion systems are applied [6]. The one-step systems are operated at TS-concentrations of 10-15%, called wet-fermentation, or at TS-concentrations of 25% and more, called dry-fermentation. Wet-fermentation can be applied for a broad spectrum of wastes, because the process takes place in a more liquid phase by recirculation of process water. Dry fermentation can be used only for solid wastes with a TS-content between 25 and 45%. The waste treatment at dry conditions enables a reduction of the reactor volume und reduces the costs for the
Table 1. Anaerobic Solids Treatment Systems for Organic Wastes from Household and Trade

<table>
<thead>
<tr>
<th>Process name</th>
<th>Company</th>
<th>Operation</th>
<th>HRT (d)</th>
<th>TS (%)</th>
<th>Temperature (°C)</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATF</td>
<td>Haase</td>
<td>Continuously</td>
<td>15-25</td>
<td>30-35</td>
<td>55</td>
<td>1,000 t/a</td>
</tr>
<tr>
<td>KOMPOGAS</td>
<td>Bühler</td>
<td>Continuously</td>
<td>15-20</td>
<td>20-40</td>
<td>55</td>
<td>10,000 t/a</td>
</tr>
<tr>
<td>ANAERGIL</td>
<td>Noell</td>
<td>Continuously</td>
<td>10-20</td>
<td>10-15</td>
<td>35-37</td>
<td>Pilot plant</td>
</tr>
<tr>
<td>BIOSTAB</td>
<td>ATU-Ing.-Gas.</td>
<td>Continuously</td>
<td>12-15</td>
<td>10-12</td>
<td>33-37</td>
<td>1,650 t/a</td>
</tr>
<tr>
<td>LINDE</td>
<td>Linde/KCA</td>
<td>Continuously</td>
<td>12-15</td>
<td>no data</td>
<td>33-35</td>
<td>Pilot plant</td>
</tr>
<tr>
<td>ROEDIGER</td>
<td>Blöfinger &amp; Berger</td>
<td>Continuously</td>
<td>no data</td>
<td>no data</td>
<td>33-35</td>
<td>Pilot plant</td>
</tr>
<tr>
<td>WAASA</td>
<td>Thyssen</td>
<td>Continuously</td>
<td>14-21</td>
<td>10-12</td>
<td>50-55</td>
<td>Pilot plant</td>
</tr>
<tr>
<td>WABIO</td>
<td>Babcock</td>
<td>Continuously</td>
<td>7-10</td>
<td>10-12</td>
<td>33-37</td>
<td>6,500 t/a</td>
</tr>
</tbody>
</table>

The two-step process is more expensive but results in higher removal efficiencies and better process reliabilities at variable waste conditions. More than 15 different process types were developed within the last five years, but only few types have been installed in industrial-scale with treatment capacities up to 1,500 tons per year (t/a). The most important process types and their characteristic data are shown in Table 1.

One-step systems with wet fermentation are most often applied for separate collected household wastes. The process is operated at mesophilic or thermophilic temperature conditions with hydraulic retention times between 7 and 21 days. Per ton of waste-input between 100 and 150 m³ biogas is formed. The typical reactor configurations which are used for wet- and dry-fermentation are shown in Figure 11.

For one-step digestion with wet-fermentation special mechanically mixed reactor systems are used which mixes the waste sufficiently to prevent scum formation by floating of solid wastes. In the ANAERGIE-Process, which was developed by the German Federal Agricultural Research Centre (FAL), mixing is achieved e.g. by a screw agitator which acts downwards within a draft tube inside a completely filled loop reactor [7]. Dry-fermentation systems use tower reactors which are operated in downflow mode without internal mixing or horizontal channel reactors with low rotating horizontal agitators. Two-step processes will become more important if impurities, e.g. heavy metals, must be
separated in order to meet the quality standards for land application of the treated residues.

CONCLUSIONS

Anaerobic digestion processes become more and important in Germany for the treatment of high loaded wastewater, slurries and solid organic wastes from agriculture, agro-industry and the municipal sector. The treatment process is not only important for pollution control and biogas formation but also for the disinfection of wastes and for the recycling of nutrients to agriculture. In addition anaerobic treatment processes become important in the future for the reduction of climate affecting greenhouse gases which are formed during storage, dumping or application of untreated organic wastes.

The increasing charges for effluents and solid wastes and new regulation which limit the disposal of wastes promotes the implementation of anaerobic treatment system. For achieving sustainability in agriculture, food and agro-industry but also in the municipal sector the biomethanation processes will play a key role in the future. The process will be applied also in some time for the conversion of energy crops into biogas for the production of renewable energy.

REFERENCES